ROYAL AIR FORCE
TECHNICAL COLLEGE

PRECIS
OF
INSTRUMENT SUBJECTS

COPY No. 1

PRECIS

OF LECTURES

IN

INSTRUMENT SUBJECTS

C O N T E N T S

Precis No.1	Fundamentals of Electronic Engineering.
Precis No.2	Instructions on Laboratory Work and Experiments.
Precis No.3	Magnetism and Compasses.
Precis No.4	Gyro Gunsights.
Precis No.5	Oxygen.
Precis No.6	Link Trainer.
Precis No.7	General and Electrical Instruments.
Precis No.8	Instrument Workshop Practice.
Precis No.9	The Gyroscope.
Precis No.10	Mk.8 Auto Pilot.
Precis No.11	Mk.9 Auto Pilot (to be issued later).
Precis No.12	Bombsights (to be issued later).
Precis No.13	Navigational Instruments (to be issued later).

A M E N D M E N T S

A.L.No.	Date	Subject	Sig.	A.L.No.	Date	Subject	Sig.

ELECTRICAL & INSTRUMENT SECTION

HENLOW DIVISION, R.A.F. TECHNICAL COLLEGE

THE FUNDAMENTAL PRINCIPLES OF ELECTRONIC ENGINEERING

Instrument Precis No.1

THE BASIC THEORY OF ELECTRONICS

The Electronic Structure of Matter

It is now an accepted theory that all substances are composed of molecules, the molecule being the smallest particle which still retains the characteristic properties of that substance. The molecule consists of two or more similar atoms in the case of elements e.g. gold, suplhur, hydrogen, etc., there being some 92 different known elements.

This pure gold consists of molecules each made up of atoms of gold, whilst a compound substance such as water consists of molecules composed of two atoms of hydrogen, and one of oxygen.

Reference:

A.P. 1093. Part 2. Chapter 1. Paras. 1 to 15.

The Electron

Investigation of the atom revealed that it was not a single solid substance, but was a minute solar system, consisting of a positively charged nucleus which represents almost the whole of the mass of the atom with negatively charged electrons revolving around this nucleus in plane - tary orbits. The structure of the heavier atoms is extremely complex, but it is agreed that each atom in the normal state has as many positive as negative charges and is therefore electrically neutral. Now the chief difference between a metal or a substance which is an electrical conductor, and one that is not, is that the electrons on the outer orbits of the atoms are continually moving from one atom to another, whilst in the case of the insulator the electrons are more tightly bound, so that they do not leave the atom under normal circumstances. Since the electron represents a negative charge, when an electron leaves an atom, that atom is left positively charged, and it is known as a positive ion. When an atom gains an extra electron it is negatively charged, and it is known as a negative ion.

The electrons in a conductor are always moving from atom to atom in an irregular manner, such that at any one instant there are as many electrons moving in one direction as another. When a battery or other source of electromotive force is applied to a conductor, the electrons being negative are attracted to the positive terminal, and there is now a continuous movement of electrons from the negative towards the positive end of the conductor; electrons entering the battery or generator at the positive terminal and being forced through it, leaving it at the negative terminal. It will be seen that this flow of electrons is in the opposite direction to the conventional flow of electric current. Fig.1 is an attempt to show this effect.

When a potential difference is applied to an insulator, the orbits of the electrons are strained from the circular to the elliptical. This

.../displacement

displacement of the orbit represents the energy stored in a condenser, which is basically two plates of metal separated by an insulator, when charged by the application of a potential difference to the plates. Fig.2 is an illustration of the effect.

Thermionic Emission of Electrons.

As previously stated the electrons of the outer "shell" of an atom which is a conductor, are continually moving from atom to atom; the velocity with which they move may be increased by heating the conductor. When the temperature is raised to a certain value, the velocity of the electron is such that it possesses sufficient energy to break from the surface of the conductor into the surrounding space. The number of electrons emitted per unit area depends upon the temperature to which the conductor is raised, and also upon its composition. The emitter of electrons is known as the CATHODE, and if it is coated with oxides of the alkaline earths, or thorium oxide, a considerable emission is obtained at temperature below bright red heat. A cathode so coated is known as a "dull emitter", in contrast to a "bright emitter" in which the cathode is a simple metal wire (usually tungsten).

The cathode may be heated by passing current through it, in which case it consists of a filament of wire, and is known as a directly heated cathode. If the filament is enclosed in an oxide coated metal tube as shown in sketch, the tube emits electrons when the filament is energised, and is then known as an indirectly heated cathode. The filament (sometimes referred to as the heater) is not regarded as an active electrode.

Reference:

A.P. 1093. Chapter VIII. Paras. 1, 2, 3, 4, 5, 6 & 7.

Classification of Electron Tubes

(a) High Vacuum Tubes (The gas remaining in the tube after evacuation plays no part in the electron motion).

(1) Thermionic tubes - (having a heated, thermionically emitting cathode).

(2) Phototubes - (having a photoelectrically emitting cathode).

(b) Gas Tubes (gas, purposely inserted plays a major part in the operation).

(1) Thermionic Tubes.

(2) Photo Tubes.

(3) Gold-cathode tubes (unheated cathode - emission by secondary emission or field emission).

When the above broad headings have been satisfied, a further classification takes place according to the number of electrodes in the tube.

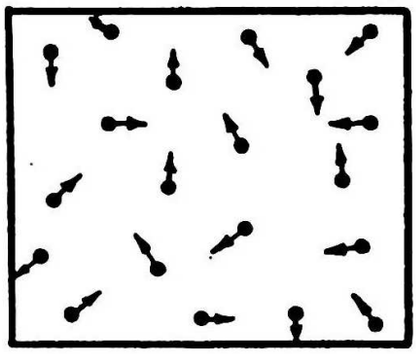
Diode - 2 electrodes - cathode and anode (or plate)

Triode - 3 electrodes - cathode, control grid, anode.

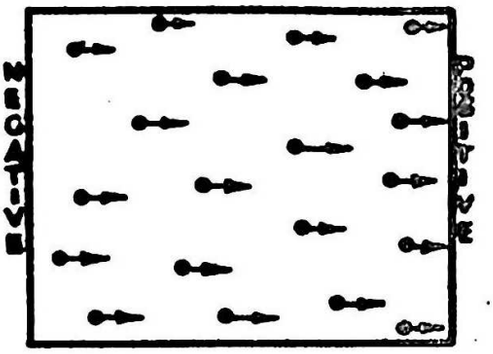
Tetrode - 4 electrodes - cathode, control grid, screen grid, anode.

Pentode - 5 electrodes - cathode, control grid, screen grid, suppressor grid, anode.

.../The tubes

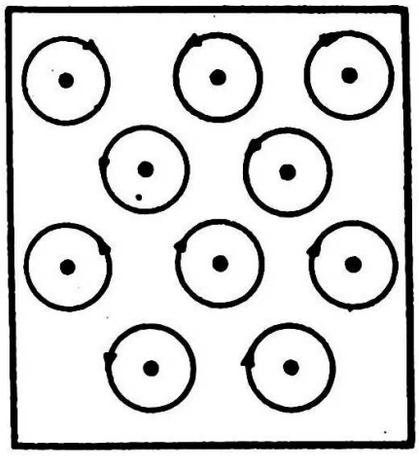


PATH OF ELECTRONS BEFORE A POTENTIAL IS APPLIED TO A METAL

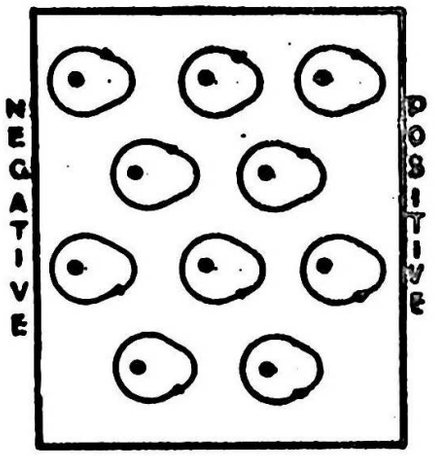


PATH OF ELECTRONS AFTER A POTENTIAL IS APPLIED TO A METAL

Fig. 1



ELECTRON ORBITS IN AN INSULATOR BEFORE A POTENTIAL IS APPLIED



ELECTRON ORBITS IN AN INSULATOR AFTER A POTENTIAL IS APPLIED.

Fig. 2

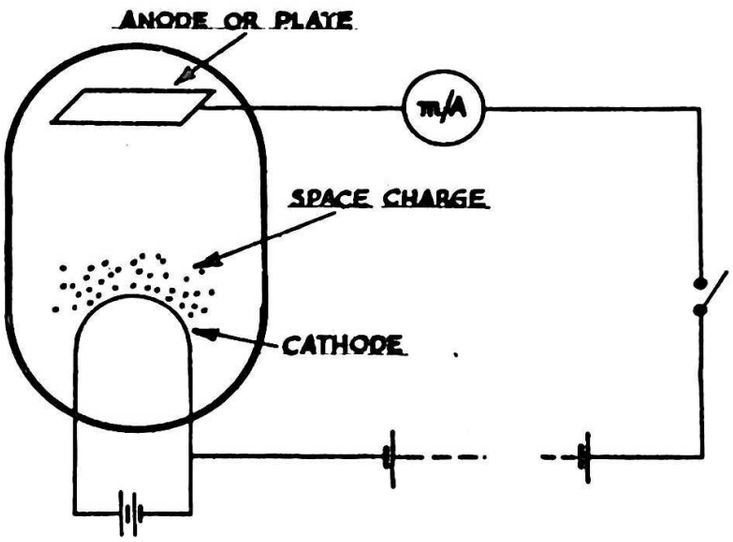

ANODE OR PLATE
mA
SPACE CHARGE
CATHODE

Fig. 3

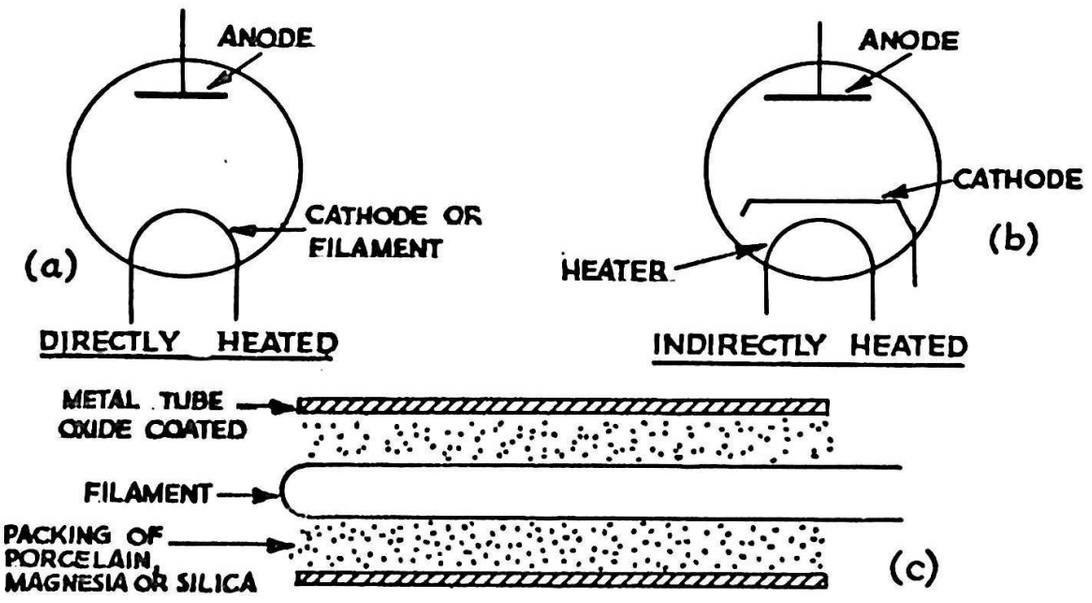

ANODE
CATHODE OR FILAMENT
(a)
DIRECTLY HEATED
ANODE
CATHODE
HEATER
(b)
INDIRECTLY HEATED
METAL TUBE OXIDE COATED
FILAMENT
PACKING OF PORCELAIN, MAGNESIA OR SILICA
(c)

Fig. 4

The tubes are named in accordance with the number of electrodes:

Hexode (6); Heptode (7); Octode (8).

The cathode may be :

(a) An unheated electrode.

(b) An incandescent filament.

(c) Combination of oxide coated cylinder and internal heater element.

This nomenclature of multi-electrode tubes is only applied to tubes having cathode, anode and grids. Tubes having additional electrodes which are not grids are referred to usually by their use i.e. Cathode Ray Tube.

The Single Diode Valve

This consists of a cathode, (the duty of which is to emit electrons) and a metal plate, known as the anode, sealed in an evacuated glass tube. When the cathode is heated, electrons are emitted, and form a cloud around the cathode, which is known as the Space Charge. The Cathode is left positively charged by the loss of these electrons, so that they will normally return to it. The effect of the Space Charge is to limit the number of electrons emitted by the cathode, since it represents a negative charge surrounding the cathode, and repels "newly" emitted electrons back to the surface of the cathode. If the plate or anode is now made positive with respect to the cathode, it will attract electrons from the space charge, so that the milliammeter will indicate a flow of electricity. Note that the flow being in the opposite direction. If the battery connected between cathode and anode is reversed, then the plate being negative will repel the electrons, and no current will take place. This phenomenon which only allows current to flow in one direction is the origin of the term valve. This valve may be used to rectify A.C., which is its chief function. The symbols adopted for the single diode valve are shown in fig.4.

Reference:

A.P. 1093. Chapter VIII Paras. 8, 9, 10, 11, 12 & 13.

Single Diode Valve as a Rectifier

The circuit fig.5 shows how the single diode valve may be used to rectify A.C. It is almost universal practise to connect the load to the cathode of the valve as shown. Note that in the external circuit electrons will flow from the anode through the transformer winding, through the load to the cathode. The conventional current being in the opposite direction, results in the cathode becoming the positive connection to the lead. The voltage applied to the plate is alternating as in fig.6, but the current through the load is unidirectional but pulsating, so that it is only useful for certain classes of work such as battery charging. Since only half of the voltage wave is rectified this valve is also known as a Half-Wave rectifier.

Reference:

A.P. 1093. Chapter IX, para. 39.

.../The Double

The Double Diode Valve

It is possible to rectify both "halves" of the A.C. cycle by the inclusion of a second plate in the valve, and connecting as shown in fig.7.

The plates are connected to either end of a transformer, which is centre tapped at C. The plates are alternately positive and negative. When A is positive, current flows (conventional) from A to cathode, to centre tap of cathode winding, through the load, back to C. During the next half cycle, B is positive and current now flows from B to cathode, continuing as before. The current through the load is now as in fig.8. This valve is sometimes known as a full wave rectifier.

Reference:

A.P. 1093. Chapter IX para. 42.

Smoothing Circuit

Most electronic circuits require a steady D.C. which is obtained by connecting a "smoothing", or "filter" circuit between the rectifier and load, as shown in fig.9. The condenser C, acts as a reservoir, becoming charged when the valve is conducting, and discharging through the load when the voltage across the valve is less than the back E.M.F. of the condenser. The voltage applied to the choke is now as shown in fig.10. This represents a steady D.C. potential on which an alternating voltage (of complex wave shape) is superimposed. Considering the alternating component only, this has a path of high impedance through the choke, and low impedance through C_2. The alternating voltage developed across C_2 and the load will thus be only a very small portion of that applied to the choke from C_1. For a load requiring 250V and 50m/a usual values for C_1 and C_2 are 8 to 12uF, and the choke 30 to 40 Henries. It will be seen from this that current is only taken from the rectifier into C_1 when the voltage is at its peak, when a sudden heavy pulse charges the reservoir C_1; care should be taken in selection of the valve that it is capable of carrying this current without overheating.

Reference:

A.P. 1093. Chapter IX, paras. 40 and 41.

Characteristic of Diode Valve

If a circuit as in fig.11 is used, and the anode current is plotted against the anode voltage, a curve as in fig.12 is obtained. This shows that as the anode voltage is raised, the anode current increases, following a law

$$I_a = K E_a^{3/2}$$

where

I_a = Anode Current

E_a = Anode Voltage

K = Constant dependent on the construction of the valve.

This law holds good whilst the cathode is emitting a sufficient number of electrons to maintain the space charge. When however the Anode Potential is raised to a value such that all the electrons emitted by the cathode are drawn directly to the anode, the space charge ceases to exist, and the anode voltage ceases to rise with further increase of anode voltage. This condition is known as saturation. Now the heat developed at the anode is a product of the number of electrons arriving, and their velocity. The first of these factors is proportional to the anode current,

.../and the

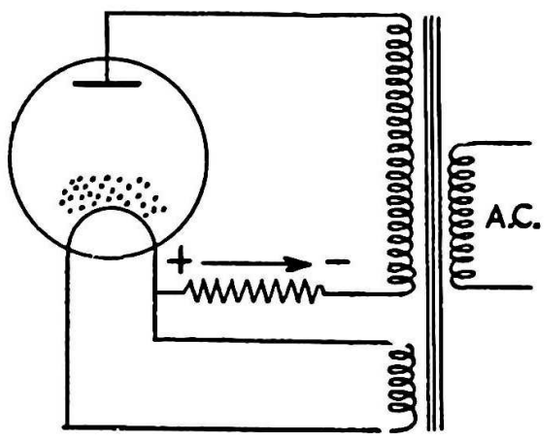


Fig. 5

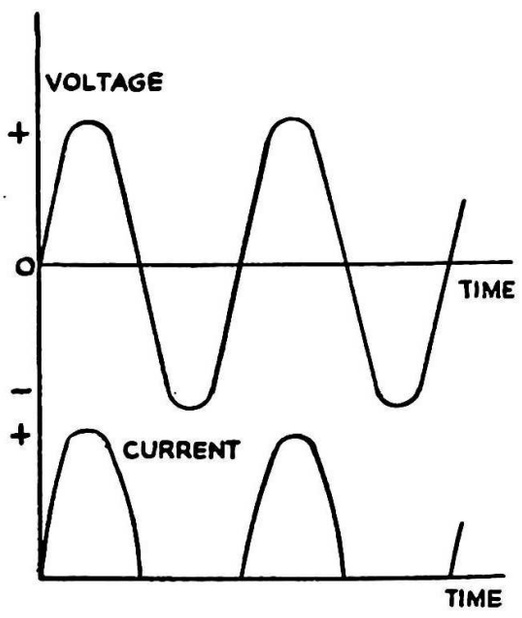


Fig. 6

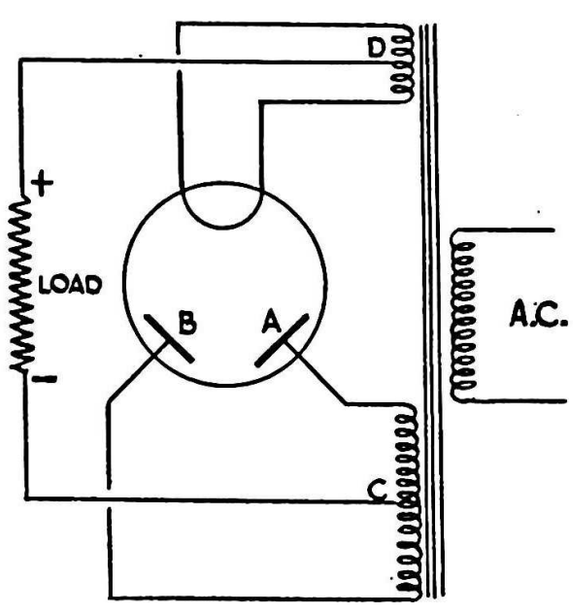


Fig. 7

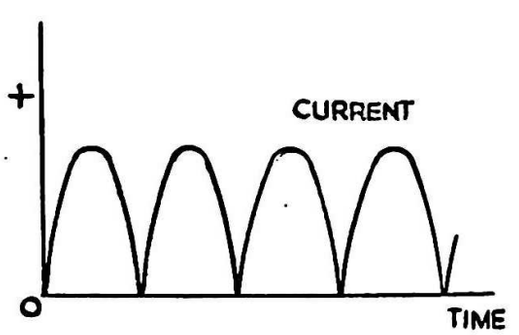


Fig. 8

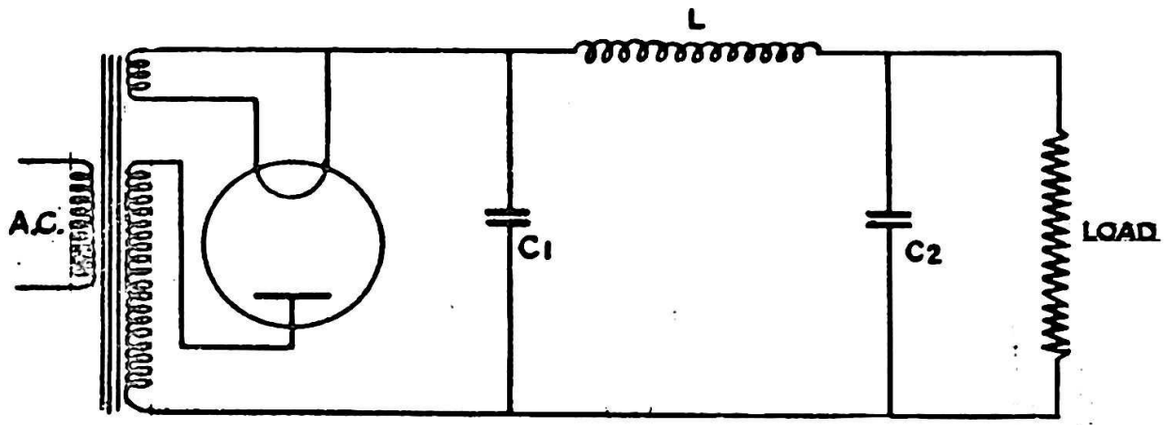


Fig. 9

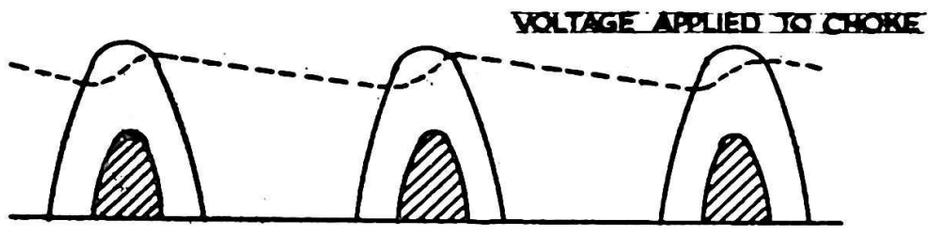


Fig. 10

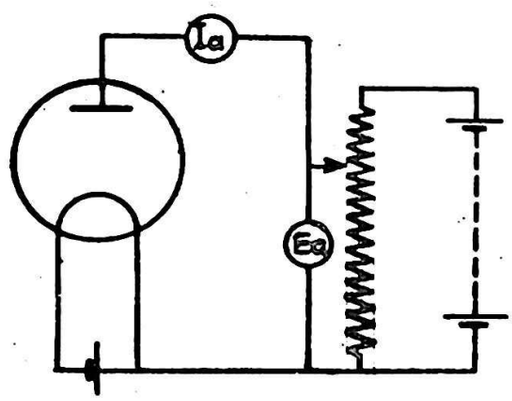


Fig. 11

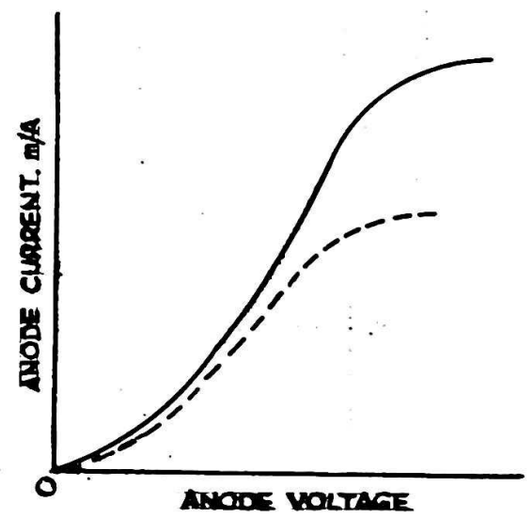


Fig. 12

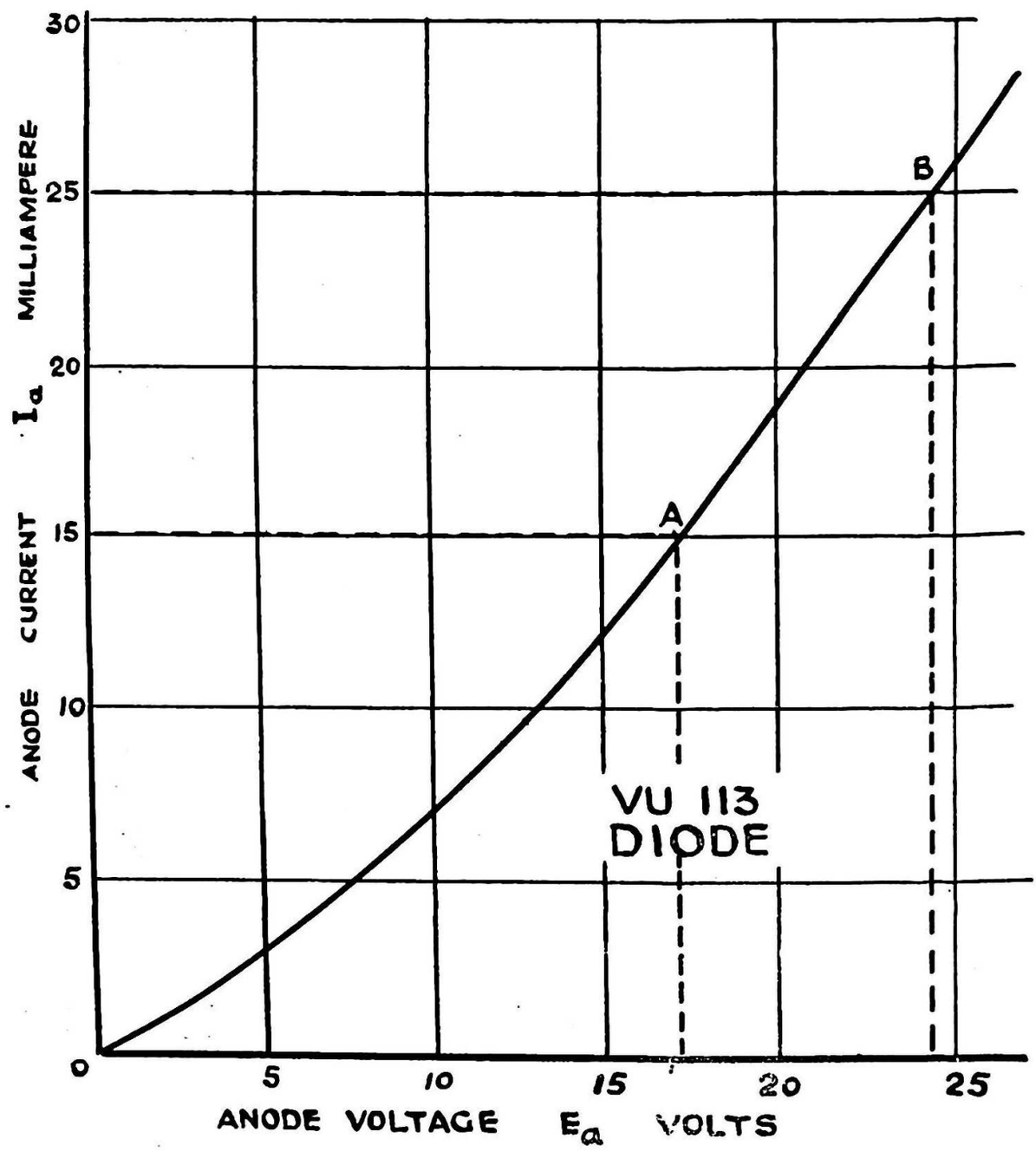

30
25
20
15
10
5
0
ANODE CURRENT I_a MILLIAMPERE
A
B
VU 113
DIODE
5
10
15
20
25
ANODE VOLTAGE E_a VOLTS

Fig. 13.

and the second to the anode voltage. The heat developed is thus proportional to the Wattage that the valve is handling. The anode is capable of dissipating a given amount of heat, and if this value is exceeded, the valve becomes overheated, which in a short time results in the electron-emitting surface of the cathode being "boiled" off, making the valve useless. Values of Anode Dissipation for individual valves are quoted in the Services Radio Valve Manual A.P.1186, Vol.1, Section 8.

Should the heating supply to the cathode be reduced (by reduction of the filament voltage) the characteristic becomes as the dotted curve fig.12. Saturation occurring at a lower anode current, since the cathode will emit a smaller total number of electrons. Most valves are not designed to work up to saturation point, and are damaged if this is done.

Reference:

A.P. 1095. Chapter VIII, para.14.

Constants of the Diode

The characteristic curve of a diode relates voltage and current, and it may, therefore, be expressed in terms of resistance.

At point A fig. 13, the voltage is 17 and current is 15 m/a. Thus the resistance of the valve is:

$$\frac{17}{.015} = 1{,}130 \text{ ohms.}$$

At point B the voltage is 24 volts and current 25 m/a.

Giving

$$\frac{24}{.025} = 960 \text{ ohms for its resistance.}$$

For each point on the curve a different value is obtained the resistance at any point being known as the D.C. resistance for that particular voltage, and given the symbol $R_{D.C.}$ This value is of little practical use.

Between A and B, however, the curve is very nearly a straight line, and between these points a change of anode voltage produces a proportional change of anode current. The result of dividing this change of voltage by the change of anode current obtained is known as the A.C. resistance of the valve and is given the symbol R_A. This is a most important value and will be found quoted in the Valve Manual A.P. 1186 for each valve.

For this valve $R_A = \frac{24 - 17}{(25 - 15) \times 10^{-3}} = \frac{7}{.010} = 700$ ohms.

The Triode Valve

This valve is similar in construction to the Diode, with a fine wire mesh or grid mounted between the cathode and anode. (Fig.14). When the grid is made negative with respect to the cathode, the space charge is repelled by the grid nearer to the cathode, so that the number of electrons drawn to the anode is reduced. The grid may be made so negative that no electrons are able to escape to the anode, and the anode current ceases. When the grid is made positive to the cathode, the space charge is drawn away from the cathode so that the anode can attract electrons more readily and the anode current is

.../increased

increased. The grid can be made so positive that saturation occurs as in the Diode. When the grid becomes positive it also attracts electrons, the effect of which will be discussed later.

Constants of the Triode

The circuit shown in fig.15 is used to plot Anode Voltage against Anode Current, with fixed potentials applied to the grid. The set of curves obtained are shown in fig.16, these being known as the $I_A E_A$ characteristics.

It will be seen that these curves are parallel for the greater part of their length, and approximately equidistant. The slope of these curves indicates the A.C. resistance of the valve or R_A. Thus point A indicates grid voltage -1, Anode voltage 86. Anode current 3.3 m/a.

Point C shows grid -1, Anode voltage 120, Anode I 6.2.

Therefore $R_A = \frac{\text{Change of Anode Volts}}{\text{Change of Anode I.}}$

$$= \frac{120 - 86}{6.2 - 3.3} = \frac{34}{2.9} = 11{,}700 \text{ ohms.}$$

Reference:

A.P. 1093. Chapter VIII, paras. 15 to 22 inclusive.

Mutual Conductance (gm)

Point C. shows 6.2 Anode I. -1 grid 120 Anode V.
B. shows 3.3 Anode I. -2 grid 120 Anode V.

Thus the anode current may be increased by 2.9 m/a by increasing the grid voltage from -2 to -1. The change of Anode Current obtained by changing the grid by 1 volt, with constant anode voltage is known as the mutual conductance, and is given the symbol gm.

Aplification Factor μ

On consideration of the above it is apparent that the anode current can be changed from 3.3 m/a to 6.2 m/a by:

1. Change of Anode Voltage from 8.6 to 120 with -1 volts on the grid.
2. Change of Grid Voltage from -2 to -1 with 120 volts on the anode.

The ratio of $\frac{\text{Change of Anode Volts}}{\text{Change of Grid Volts}}$ to give the same change of anode current is known as the amplification factor μ and in this case is equal to $\frac{120 - 86}{1} = 34$

Relation between R_A gm and μ

From the geometry of the points chosen on Fig.16.

$\mu = AB$; $R_A = \frac{AB}{BC}$, $gm = BC$

so that $AB = \frac{AB}{BC} \times BC$

or $\mu = R_A \times gm$.

.../Equivalent Circuit

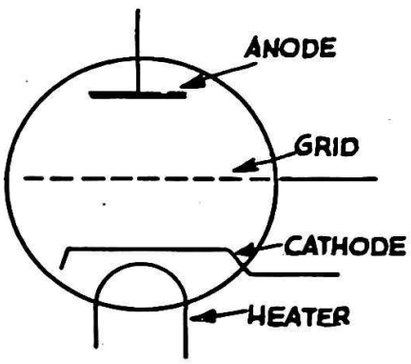


Fig. 14

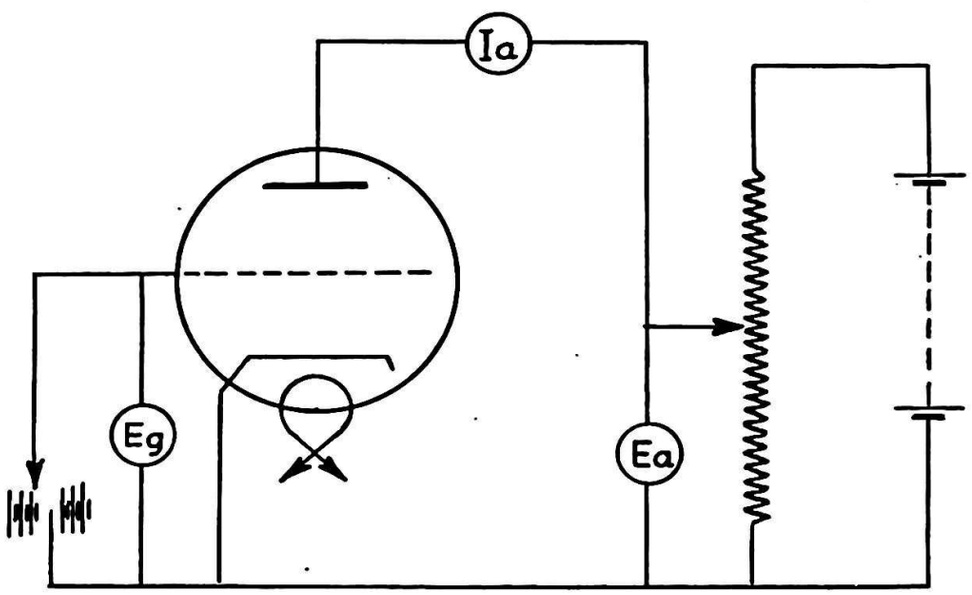
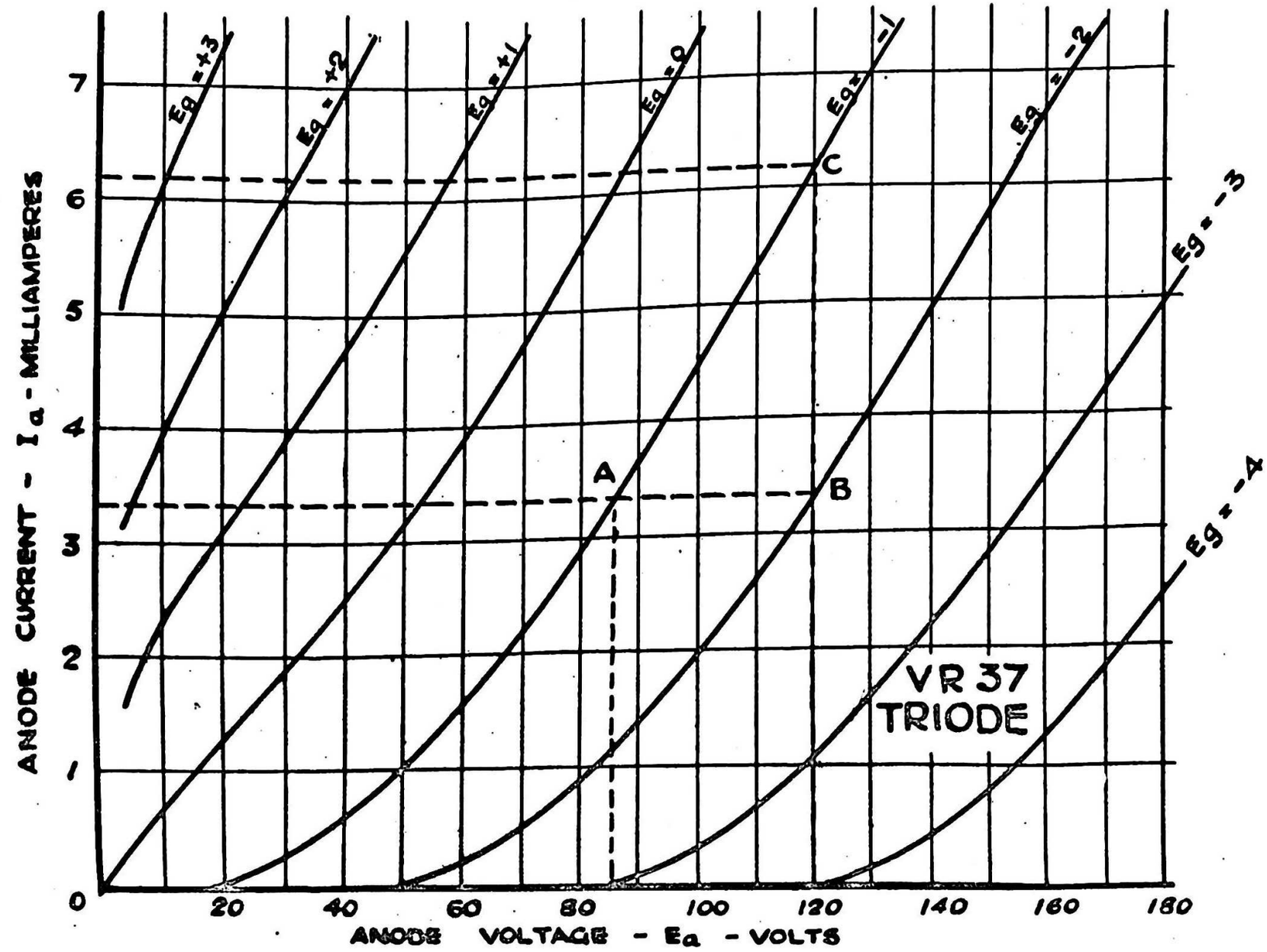


Fig. 15

Fig. 16.


ANODE CURRENT - Ia - MILLIAMPERES
ANODE VOLTAGE - Ea - VOLTS
Eg = +3
Eg = +2
Eg = +1
Eg = 0
Eg = -1
Eg = -2
Eg = -3
Eg = -4
A
B
C
VR 37
TRIODE
0
1
2
3
4
5
6
7
20
40
60
80
100
120
140
160
180

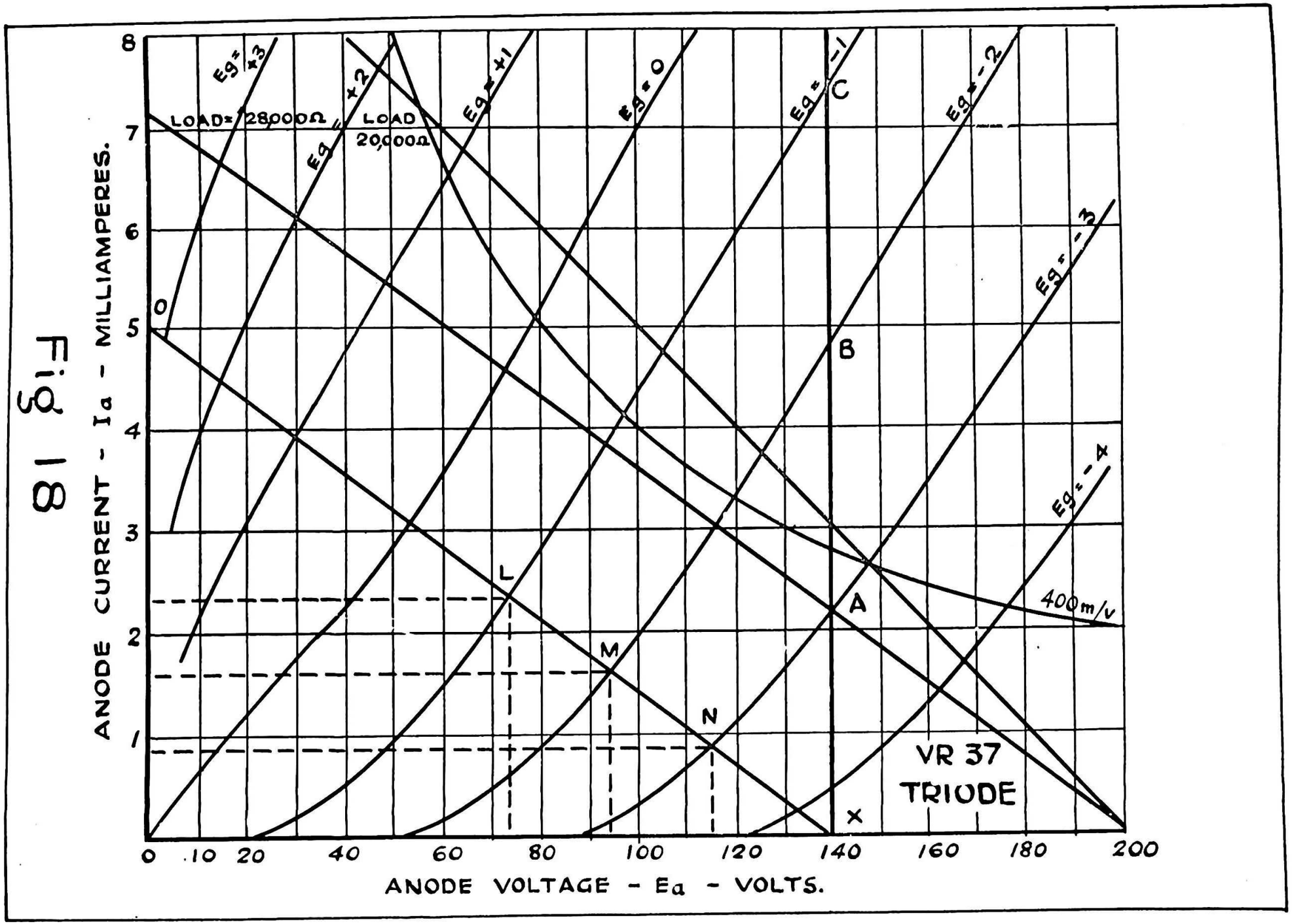


Fig 18
ANODE CURRENT - Ia - MILLIAMPERES.
ANODE VOLTAGE - Ea - VOLTS.
Eg=+3
Eg=+2
Eg=+1
Eg=0
Eg=-1
Eg=-2
Eg=-3
Eg=-4
LOAD=28000Ω
LOAD 20,000Ω
400m/v
VR 37
TRIODE
A
B
C
L
M
N
O
X
0
10
20
40
60
80
100
120
140
160
180
200
1
2
3
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5
6
7
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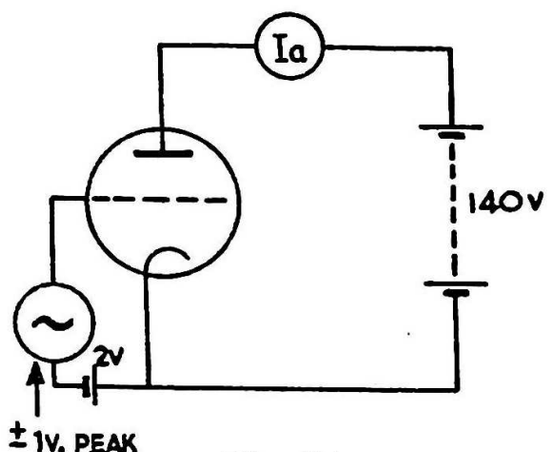


Fig. 17

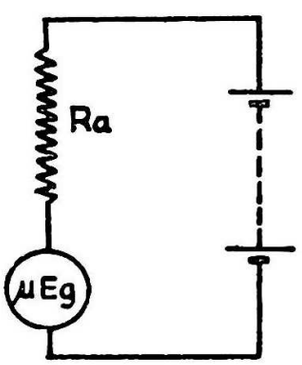


Fig. 19

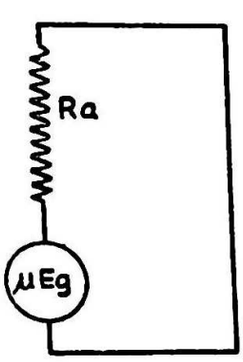


Fig. 20

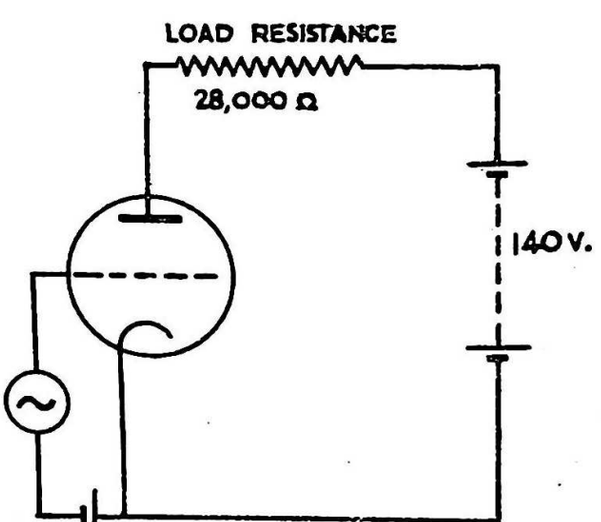


Fig. 21

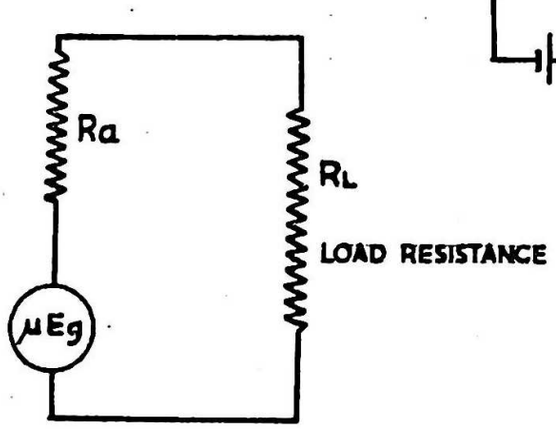


Fig. 22

Equivalent Circuit of Triode

In the circuit fig.18, a potential of 140 volts is applied to the anode, a 2 volt battery is connected in series with an alternator capable of generating an e.m.f. of one volt peak. When this alternator voltage is at zero the anode current will be 4.8 m/a as at point B in fig.18. When the alternator is generating on its positive half cycle, the grid voltage will rise from -2 to -1, the anode current rising to 7.4 m/a as at C in fig.18. On the negative half cycle the grid potential will fall to -3 volts, the anode current is now indicated 2.2 m/a. These changes in anode current would require plus or minus μ (34) volts change on the anode, if the grid had been kept at a constant potential. The circuit fig.19 shows the circuit which gives the equivalent potential. The circuit fig.19 shows the circuit which gives the equivalent conditions to what is happening in Fig.18. The battery is supplying a constant D.C. whilst the valve is acting as an alternator of μe_g volts, sending A.C. round the anode circuit and through its own Anode Resistant R_A. Thus in the anode circuit we have an A.C. superimposed on a D.C. In the circuit as shown in fig.19, the A.C. component would not be altered by removal of the battery, and since it is the A.C. component which is of greater interest to us, the equivalent circuit is usually drawn as in fig.20. Consideration of the above reveals that all the work being done by the alternating voltage μe_g is to drive current through the valve against the Anode Resistance R_A, so that there is no work being done in the external circuit, and the potential of the anode will remain unchanged. To obtain a change in voltage on the anode when the anode current changes, a load, or resistance must be connected between the battery and anode as shown in fig.21. If this resistance is 28,000 ohms, points are plotted on the graph, fig.17 for volts on the anode for various anode currents.

Thus:

Anode Current	Volts. drop Across Res.	Anode Volts
0 m/a	0	
1 m/a	28,000 x .001 = 28	140-0 = 140
2 m/a	28,000 x .002 = 56	140-28 = 112
3 m/a	28,000 x .003 = 84	140-56 = 84
4 m/a	28,000 x .004 =112	140-112 = 28
5 m/a	28,000 x .005 =140	140-140 = 0

All these points fall on a straight line as shown by OX. When the grid voltage is -1 the anode current will now be 2.35 m/a and the anode voltage 73 as at point RL when the grid voltage is -2 the anode I is 1.62 m/a and Anode Volts 94 as at point M whilst with grid at -3 the point N shows .89 m/a Anode I and 115 Anode Volts. The equivalent circuit is now as in fig.22. The student should note that the change in anode volts is less than μ, the change in anode voltage for 1 volt change on the grid being known as the gain of the valve and is equal to $\frac{\mu R_L}{R_L + Ra}$ and may be found graphically, and is equal to 94-73 = 21 from points L and M. Note also that as the grid voltage rises from -2 to -1 the anode voltage falls from 94 to 73, thus the change in voltage on the anode is in antiphase to that on the grid.

Anode Dissipation Curve

As in the diode valve, the Anode is capable of dissipating so much heat. A curve can be drawn on the graph such that all points on it represent the permissible wattage. To illustrate, if this valve is capable of dissipating 400 Milliwatts the curve would be as shown in fig.17. Now the choice of battery voltage and load line resistance, is limited by this dissipation curve, so that the normal operating point is below this line. Thus if the battery voltage was 200 volts, 28,000

.../would be

would be permissible, whilst a resistance of 20,000 ohms would cause the valve to operate above this curve if the battery voltage was 200. 400 milliwatts has been taken as an example, the V.R. 37 has actually a higher value of anode dissipation.

Graph of Triode Valve - Grid Voltage/Anode Current with fixed Anode Voltage

Using the circuit fig.15, curves are plotted, the Anode Voltage at 140 and 200 volts.

(a) With no resistance in the Anode circuit, these being known as Static curves.

(b) With 28,000 ohms in the Anode lead, these being known as the dynamic curves for this particular resistance.

The curves are shown in fig.23.

From the static curves the constants R_a gm and μ may be obtained in a similar manner to the method used with the $I_A E_A$ characteristics of fig.15.

The dynamic curves are of more interest. It will be seen that their slope is less than the static.

Class A Operation

Consider the valve with a steady bias of -2 volts, with an alternating voltage of plus and minus 1 superimposed, fig.21, battery voltage 140 and anode lead resistance of 28,000. The alternating voltage will from now on be referred to as the signal. When the signal is zero, the anode current will be 1.62 m/a from projection as on fig.23. When the signal becomes positive the anode current will rise to 2.35 m/a, and fall to .89 m/a when the signal is negative. The change of anode current is proportional to the change of grid voltage under these conditions, since we are operating on the straight portion of the dynamic curve. Note that the average value of the anode current is not changed by the grid signal, a milli-ammeter in the anode circuit would continue to read 1.6 m/a if the frequency was above 20 c/s as it would not be able to follow the fluctuations. This type of operation, known as Class A is used when the valve has to amplify a signal. From fig.23 it will be seen that the straight portion of the dynamic curve is greater when the battery voltage is increased to 200 volts. This would allow us to apply a signal of greater magnitude than is possible with 140 volts supply, before the anode current changes were not proportional to the grid voltage changes. When the grid becomes positive the curve ceases to rise at the same rate, finally flattening out. The reason for this will be found by studying fig.18 when it is seen that the maximum possible current, with 140 volts supply, and 28,000 ohms possible resistance is 5 m/a.

When the grid is positive or in the case of some valves slightly negative, the grid attracts electrons in the same manner as the anode. This grid current imposes a load on the grid circuit, which will have adverse effects upon this circuit unless it has been designed to provide the necessary power. For this reason the bias value and supply voltage is chosen so that the grid does not rise above about -1 volts.

Reference:

A.P.1093. Chapter XI, para. 4.

Chapter X, para. 35.

.../Power Output

$$Ra = \frac{\text{CHANGE IN Ea}}{\text{CHANGE IN Ia}} = \frac{200-140}{BC} = 1900\,\Omega$$

$$9m = \frac{\text{CHANGE IN Ia}}{\text{CHANGE IN Eg}} = \frac{BC}{AB} = 2{\cdot}8\ \text{m A/V}$$

$$\mu = \frac{\text{CHANGE IN Ea}}{\text{CHANGE IN Eg}} = \frac{200-140}{AB} = 34$$

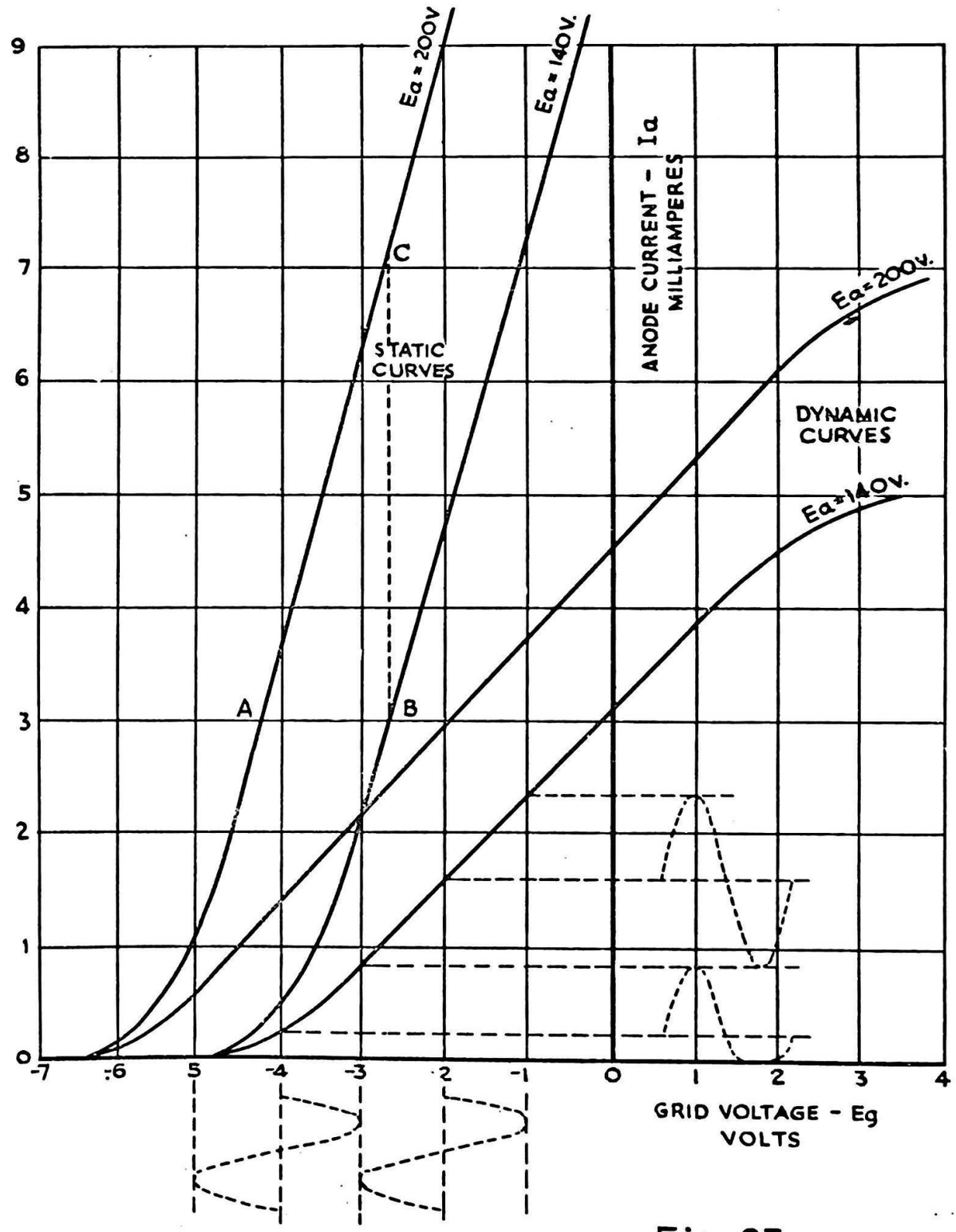


Fig. 23

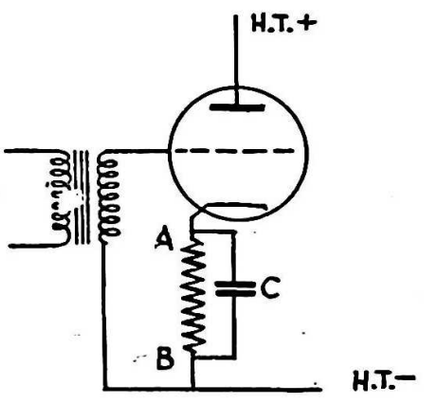


Fig. 24

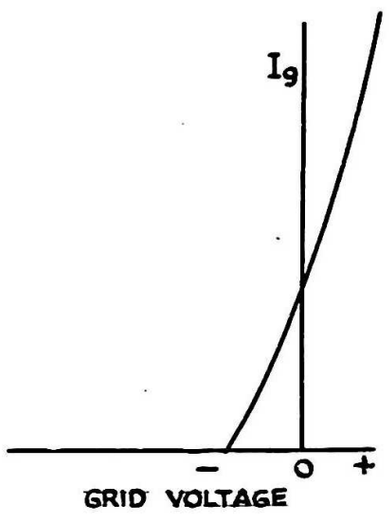


Fig. 25

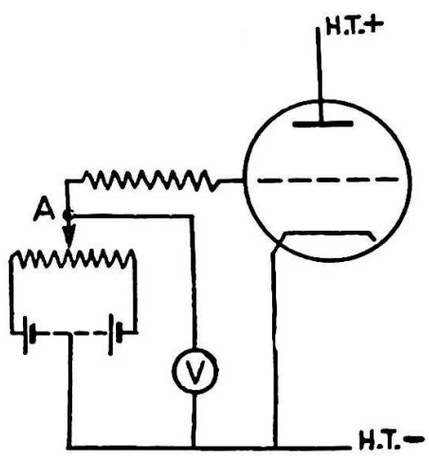


Fig. 26

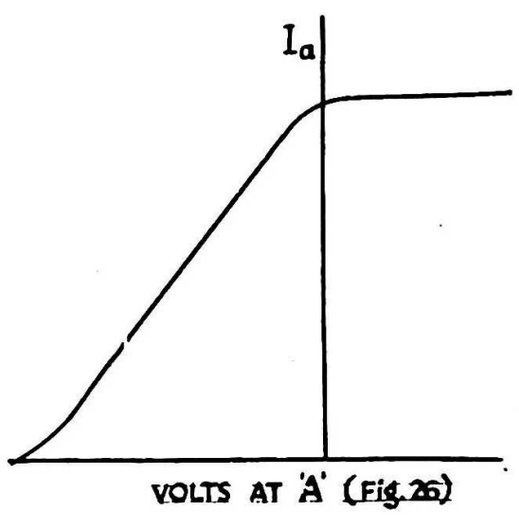


Fig. 27

Power Output Class A Operation

Referring to figs. 17 and 23, with 140 volt supply, 28,000 ohms load resistance -2 volt bias, and a 1 volt signal on the grid, the total change of voltage on the anode (and across the load resistance) is:

115 - 73 = 42 volts.

The R.M.S. value of this wave is $\frac{42}{2 \times \sqrt{2}}$ = 14.8 volts

The Anode Current change is 2.35 - .89 = 1.46 m/a.

The R.M.S. value being $\frac{1.46}{2 \times \sqrt{2}}$ = .515 m/a.

The wattage developed is therefore 14.8 x .515 = 7.62 milli/watts

or $\frac{42 \times 1.46}{2 \times \sqrt{2} \times 2 \times \sqrt{2}} = \frac{42 \times 1.46}{8}$ = 7.62 milliwatts

Thus when a valve is stated to be capable of an output of 2 watts undistorted power, it means that the total voltage change multiplied by the total current change, and divided by 8 gives 2 watts; and that this is obtained by operation under Class A conditions, on the straight section of the dynamic curve.

Class B Operation

If the bias voltage is increased to -4 volts, referring to fig.23, the no signal anode current will now be seen to be .2 m/a. On the positive half cycle of the signal, the anode current rises to .8 m/a, and falls to zero on the negative half cycle. The Anode Current wave now appears as in the case of the half wave rectifier, and for this reason, this type of operation is sometimes known as "bottom bend rectification". The average anode current will now be increased on application of the signal, and this method is used when it is desired to operate a sensitive relay in the anode circuit by applying an alternating voltage to the grid.

Reference:

A.P. 1093. Chapter XI, para. 4.
Chapter X, para. 35.

Automatic Bias

If a resistance is connected in the cathode return lead as in fig. 24, the steady anode current of the valve causes a voltage drop so that A is at a higher potential than B. The grid being connected to B will, therefore, be at a lower potential than the cathode, or negative with respect to it. The resistance is calculated by Ohms' Law when the bias required and the steady anode current are known. Thus a power valve may require a bias of 30 volts, and have an average anode current of 60 m/a.

Than R = $\frac{30}{.06}$ = 500 ohms.

Note in this case that the wattage dissipation through the resistance is 30 x .06 = 1.8 watts, so that the resistance must be capable of approximately 2 watts dissipation.

.../The condenser

The condenser C is known as "by-pass" as its function is to keep the voltage drop across A.B. constant when the anode current varies, by "by-passing" the A.C. component of the anode current. Without this condenser the gain of the valve is somewhat reduced; consider the grid receiving a positive signal, the anode current would increase, so that the voltage drop A.B. would increase, making the cathode more positive, and thus reduce the potential difference between the grid and cathode. In practise the condenser is sometimes omitted when it is desired to reduce the gain of the valve for some reason or other.

Reference:

A.P. 1093. Chapter XI, para. 134.

Grid Current

If a graph is made of grid volts against grid current, fig.25, it will be found that the grid collects electrons while it is slightly negative; the actual starting point varies with individual valves, but an average figure is approximately 1 volt negative. This is mainly due to the fact that when the cathode is emitting electrons, it being deficient of electrons will attract them back to itself either directly from the space charge, or via the grid. To prevent them returning via the grid a negative potential must be applied to the grid, which as stated above is usually about one volt negative. When the grid is actually positive to the cathode, the grid then collects electrons in the same manner as the anode. If a resistance of about half a megohm or more, fig.26, is connected in series with the grid, a great change is made in the grid volts/anode current characteristics when the voltage applied rises above the point where grid current starts. Plotting Voltage at A against anode current (Fig.26) the curve shown in fig.27 is obtained. This curve is as a normal $I_A E_g$ curve whilst A is negative. This is due to the grid current, causing a voltage drop through the resistance, so that although point A rises in potential, the potential of the grid only rises a very small fraction of this voltage, so that it can almost be considered to remain at a constant potential. This effect is used on the C.1 Autopilot for sensitivity control, and will be discussed later in Part 2.

Reference:

A.P. 1093. Chapter VIII, para. 27.

Chapter X, paras. 20 to 26 (inclusive)

The Grid Leak Detector

With the circuit shown in fig.28 the potential of the grid will adjust itself to the point at which grid current commences. The anode current will be as indicated on the graph. Consider an A.C. signal being applied. When the signal becomes positive the condenser will convey this charge to the grid, which will attract electrons from the cathode.

These electrons will not be able to return to the cathode due to the condenser, but will accumulate on plate B of the condenser. The condenser becomes charged on this positive half cycle, with plate B negative since it now has a surplus of electrons. On the negative half the charge on the condenser is unchanged, as there will be no grid current. On the next positive half cycle the grid will attract more electrons when it again becomes positive to the cathode (at the peak of the wave), further increasing the charge on the condenser.

This process continues until the charge on the condenser is equal to the peak voltage of the signal, when the grid will be unable to attract further electrons from the cathode. This causes a drop in the average potential of

.../the grid,

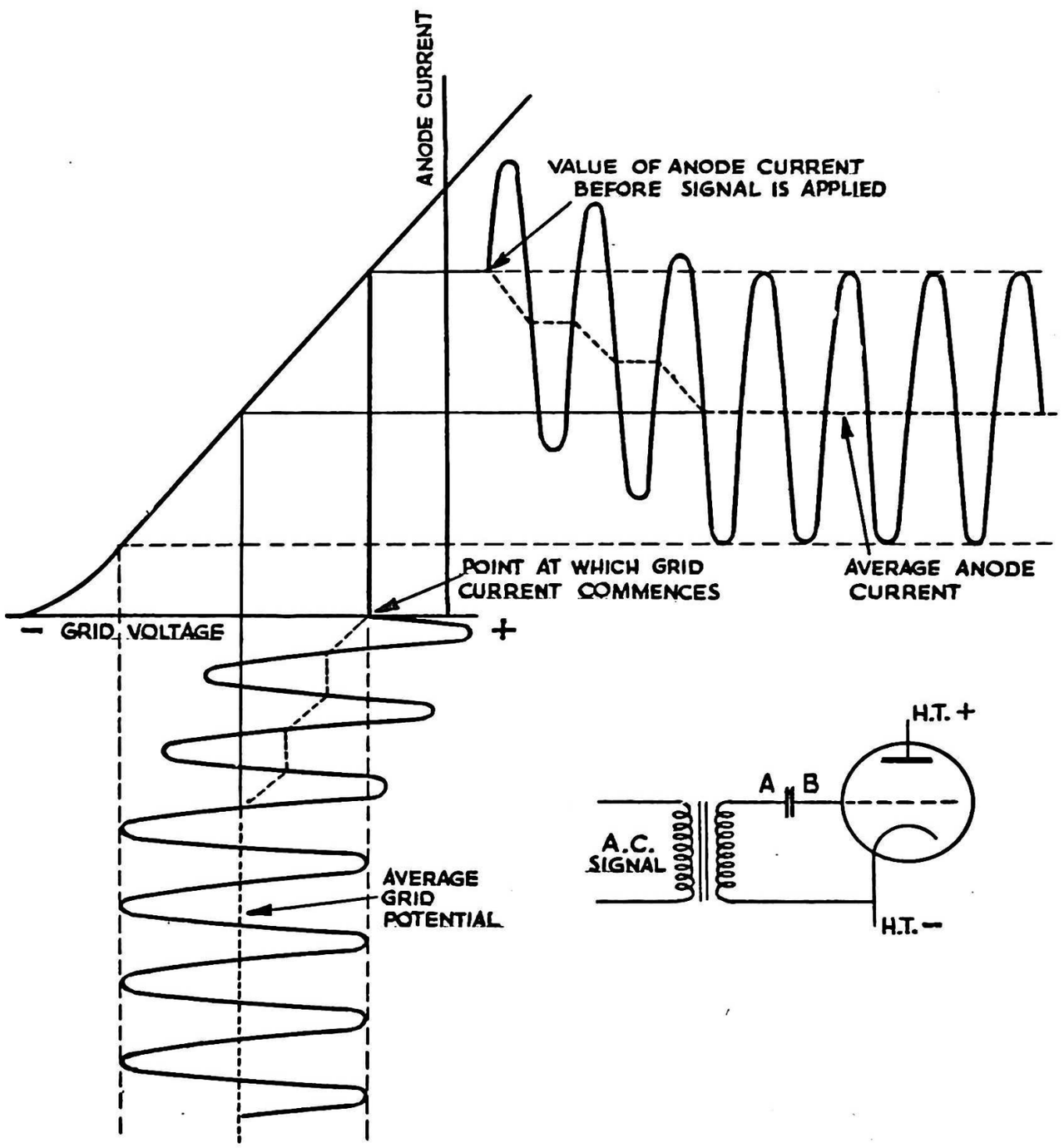

ANODE CURRENT
VALUE OF ANODE CURRENT
BEFORE SIGNAL IS APPLIED
POINT AT WHICH GRID
CURRENT COMMENCES
AVERAGE ANODE
CURRENT
— GRID VOLTAGE +
AVERAGE
GRID
POTENTIAL
H.T. +
A
B
A.C.
SIGNAL
H.T. —

Fig. 28

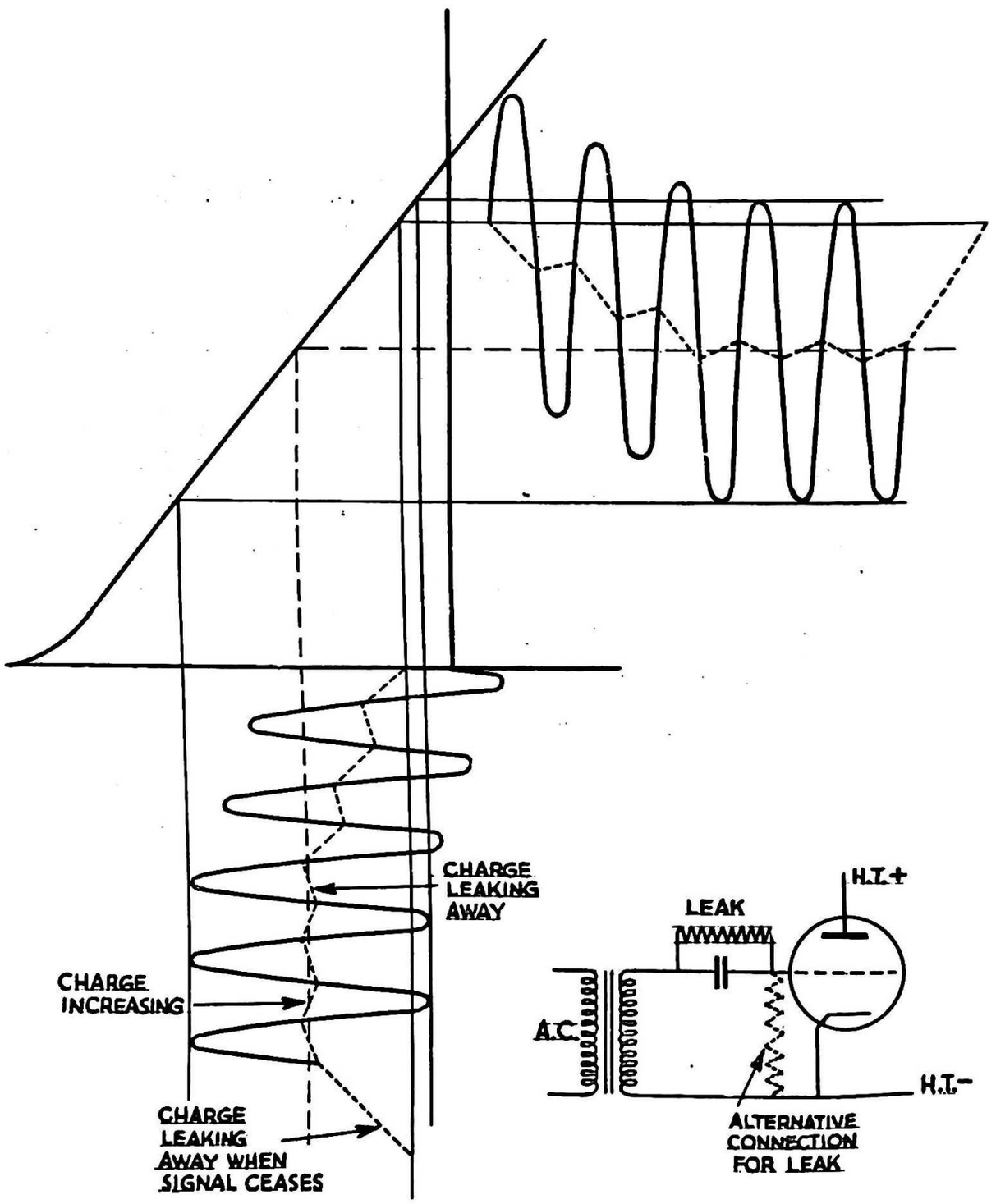

CHARGE LEAKING AWAY
CHARGE INCREASING
CHARGE LEAKING AWAY WHEN SIGNAL CEASES
H.T.+
LEAK
A.C.
H.T.-
ALTERNATIVE CONNECTION FOR LEAK

Fig. 29

the grid, and as a result the average anode current falls. A relay could be connected in the anode circuit, and being closed could be opened by the application of an A.C. signal, causing a drop in the average anode current. Such a circuit would not be capable of continuous operation, as when the signal ceased, the condenser would be left charged. It is necessary, therefore, to arrange a means of discharging the condenser so that when the signal ceases the grid is able to discharge through a resistance, usually 1 to 2 megohms, as shown in fig.29. This resistance is referred to as a leak.

When this leak is connected the charge on the condenser falls slightly on the negative half cycles, and the average charge on the condenser now becomes a little less than the peak voltage, so that the electrons gathered on the positive peaks are equal to those lost through the leak on the negative half cycles.

Although this device is mainly used in radio work, it will be found in Electronic Engineering in various forms, and in oscillatory circuits.

Reference:

A.P. 1093. Chapter VIII, para. 23.

Chapter X, paras. 20 to 26 (inclusive)

Inter-Electrode Capacity

In the normal triode capacity effects exist between

(a) the grid and cathode

(b) The grid and anode

(c) The anode and cathode

The capacity between grid and anode is the most important as it effects a link between the grid and anode at high frequencies, so that the valve is unsuitable when the frequency is more than 1000 k c/s without extensive circuit alterations. This effect is minimised by fitting a screen between the grid and anode, and connecting it to the cathode fig.30. The following capacity effects now exist: between

(a) grid and cathode

(b) grid and screen

(c) anode and screen

(d) anode and cathode

whilst that between anode and grid is only about one thousandth its former value. The effects (a) and (b) are in parallel, and (c) and (d) are also in parallel. The screen so connected would have a detrimental effect on the electron flow to the anode, but if the screen is made positive and connected to the cathode by a condenser the grid anode capacity is still negligible, and the electron stream somewhat assisted. The inclusion of this fourth electrode constitutes the screen grid valve or Tetrode.

Reference:

A.P. 1093, Chapter VIII, para. 31.

.../Characteristic

Characteristic of Screen Grid Valve

The screen has a potential of 80 volts applied, fig. 31 then an I_AE_A curve is taken in a similar manner to that used with the triode, fig. 32. It will be seen that the anode current curve has a negative slope between A and B. Between these anode potentials the electrons arrive at the anode plate with such velocity that they bombard it with sufficient force to free electrons from its surface. This is known as secondary emission. The electrons freed in this manner are attracted to the screen which has the higher positive charge. From B to C these electrons are reattracted to the anode, so that when the anode potential is 20% to 30% higher than the screen the screen current falls nearly to zero. The normal useful operating portion of this valve's characteristic is to the right of C. It will be seen that from this point onwards the anode current rises very slowly for increase of anode volts, so that R_A is very high. The mutual conductance gm is also fairly high compared with a triode, so that μ which equals gm x R_A is very large, and may be 500 to 2,000 depending on the valve. Since the load line must be drawn so that it cuts the curves to the right of C, the gain of the valve is somewhat limited, although it may compare favourably with a triode.

Reference

A.P. 1093. Chapter VIII, paras. 32, 33 & 34.

The Pentode Valve

This valve is a development of the screen grid valve. It has an additional screen or earthed grid fitted between the screen and the anode, fig.33, which is connected either internally or externally to the cathode. The I_AE_A curve fig. 34 has now no negative slope, and the valve may be operated over the greater part of its characteristic. The anode current rises very slowly with increase of anode volts over the working range of the valve as with the tetrode, so that the valve also has a high R_A. This "Flattening" of the anode volt anode current curve allows the valve to be used as a constant current device, since the change of anode current is practically negligible for a big change of anode voltage. The student should note that μ is again large, as gm is fairly high, and since it can be operated over most of its characteristic the valve is also suitable when properly designed for power outputs.

Reference:

A.P. 1093, Chapter VIII, para. 37.

The Beam Tetrode

The construction of this valve is shown in fig.35. Two plates which are connected to the cathode, are fitted so that the electrons are made to form a dense cloud in between them as they pass on to the anode. This forms a second space charge between the screen and the anode, so that electrons emitted by bombardment from the anode are returned to the anode by the negative charge of the electrons between the gap in the plates.

This effect demands a large number of electrons, or fairly high anode current, so that this valve is only suitable for handling fairly large powers, which is why it is sometimes referred to as the Power Tetrode, or Output Tetrode. Its I_AE_A characteristic is very similar to the pentode.

In all these valves employing a screen between grid and anode we find that for a given grid potential the total number of electrons leaving the cathode is more dependant on the potential of the screen than the anode.

.../This is

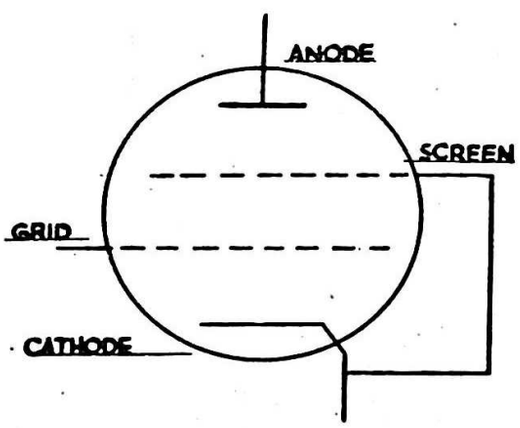


Fig. 30

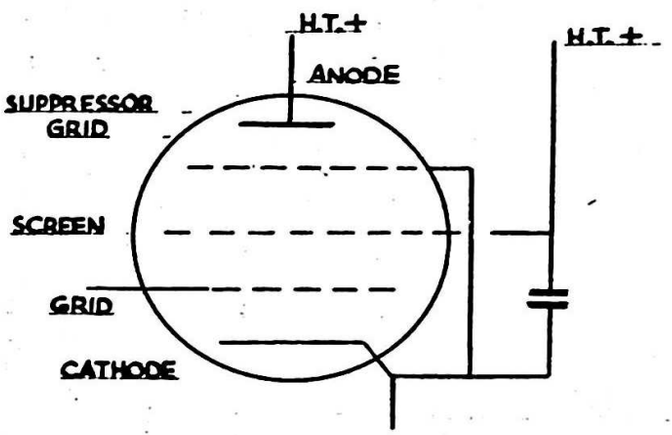


Fig. 33

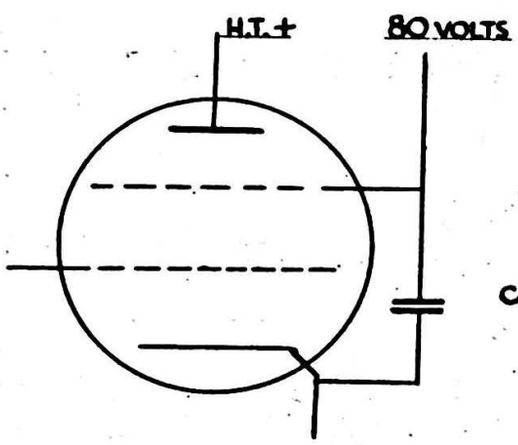


Fig. 31

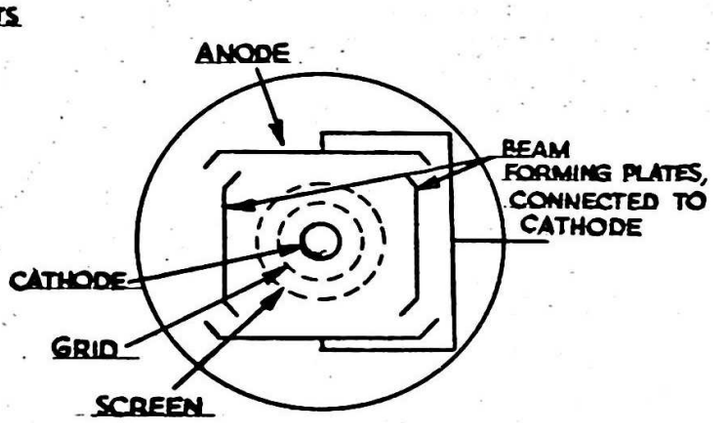


Fig. 35

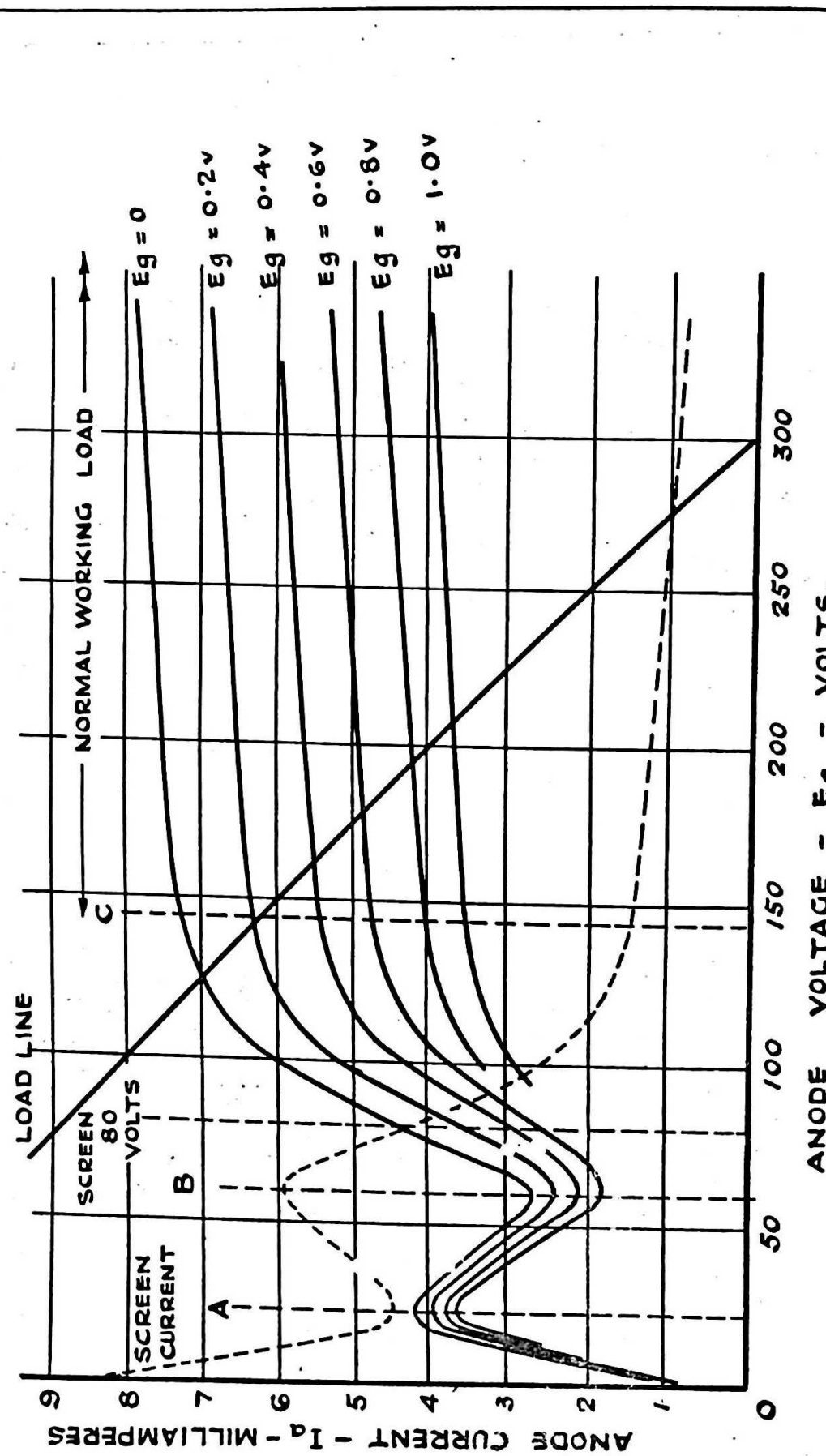

ANODE CURRENT - I_a - MILLIAMPERES
ANODE VOLTAGE - E_a - VOLTS.
Eg = 0
Eg = 0·2v
Eg = 0·4v
Eg = 0·6v
Eg = 0·8v
Eg = 1·0v
NORMAL WORKING LOAD
LOAD LINE
SCREEN 80 VOLTS
SCREEN CURRENT
A
B
C
0
50
100
150
200
250
300
1
2
3
4
5
6
7
8
9

Fig 32

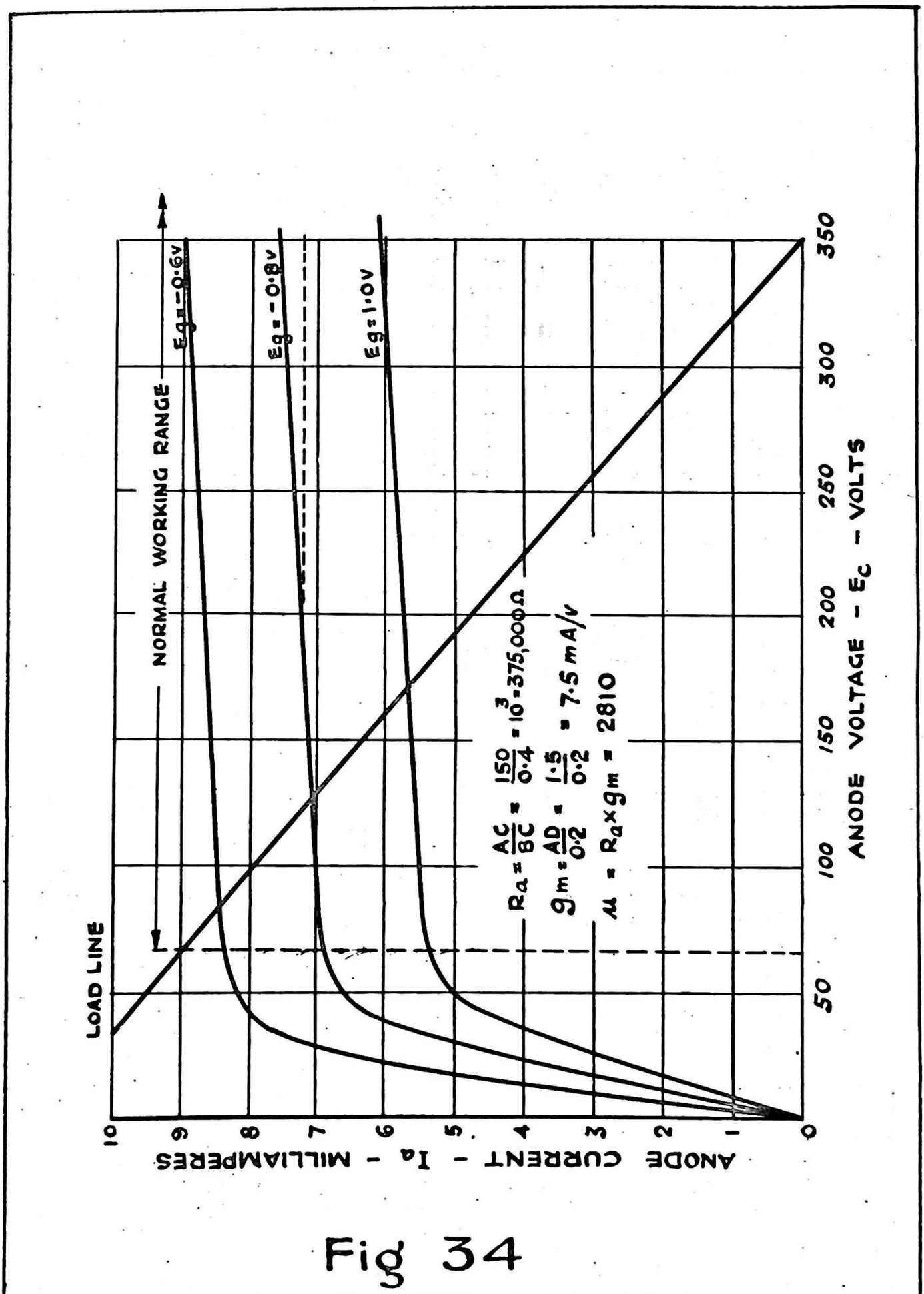
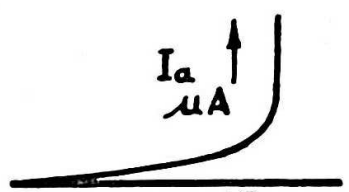
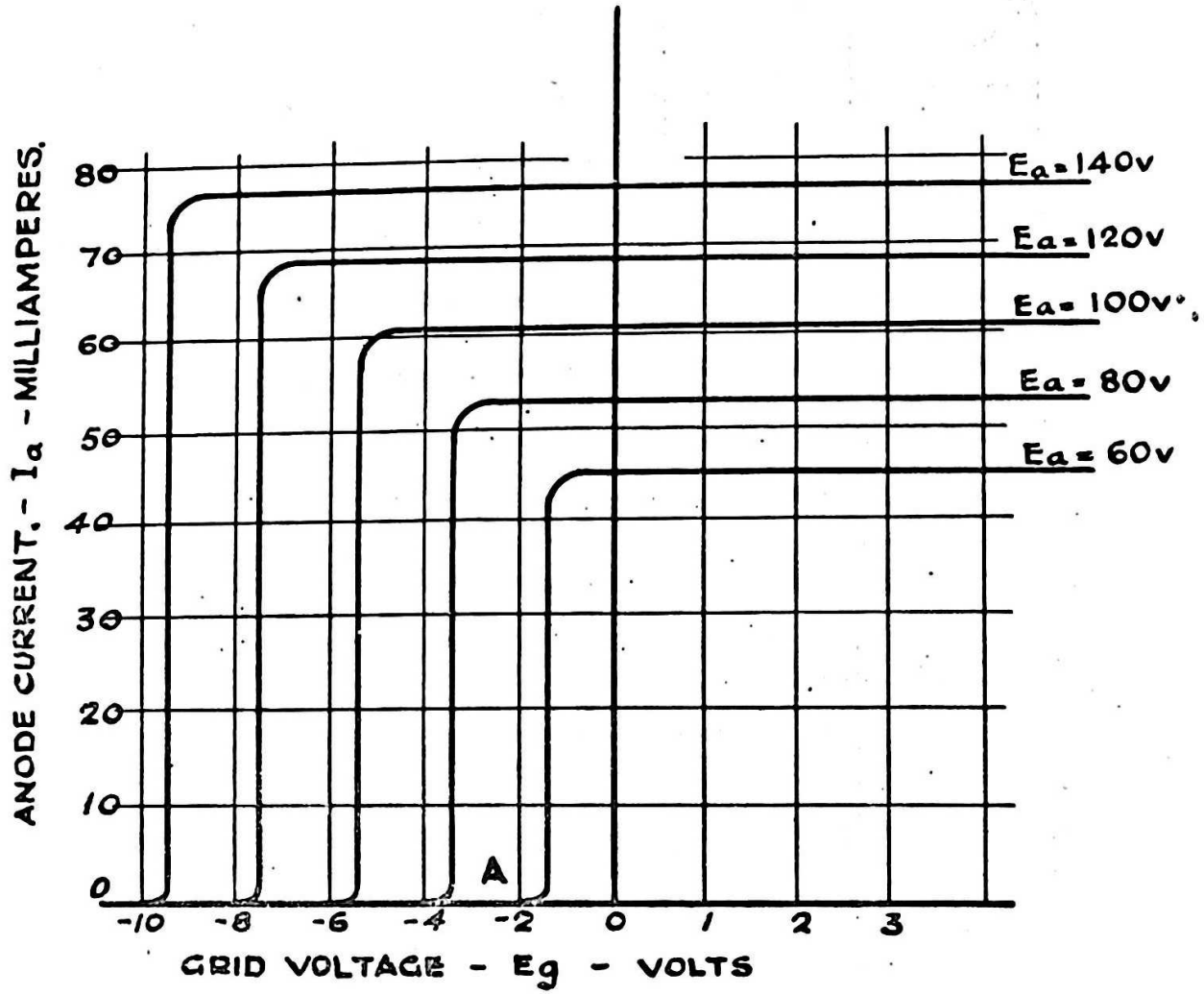

ANODE CURRENT - I_a - MILLIAMPERES
ANODE VOLTAGE - E_c - VOLTS
NORMAL WORKING RANGE
LOAD LINE
Eg=-0·6v
Eg=-0·8v
Eg=1·0v
$R_a = \frac{AC}{BC} = \frac{150}{0·4} = 10^3 = 375{,}000\Omega$
$g_m = \frac{AD}{0·2} = \frac{1·5}{0·2} = 7·5\ mA/v$
$\mu = R_a \times g_m = 2810$

Fig 34

Fig. 36.



ENLARGED SCALE AT "A"



This is because the screen shields the anode from the cathode electrostatically, so that very few lines of force extend from the anode to the cathode. It is important therefore that the correct potential is applied to the screen as otherwise the constants of the valve are considerably altered.

Gas-filled Valves

These valves are either triodes or tetrodes, usually directly heated, containing gas at a low pressure (e.g. mercury vapour at from 1 to 50u, u = $\frac{1}{10^6}$ atmospheres).

They are also known as "THYRATRONS", "GRID-GLOW" or "SOFT" valves. As the grid potential is raised from a negative value there is first of all a minute anode current, in the order of microamps, but at a certain grid potential the anode current leaps to a high value, maybe 2 or 3 amps depending on the valve. This is due to ionisation by collision. The electrons on their passage to the anode strike the electrons of the gas atoms, leaving these atoms as positive ions. Gas when ionised becomes a relatively good conductor. Once this high anode current commences, the grid has relatively little effect on the anode current, since the positive ions collect around it, and neutralise its charge. The valve will remain conducting until the potential of the anode is reduced to a very low value. Fig.36 shows the $I_A E_g$ characteristics of this valve.

Circuit Coupling

The usual source of a signal to work a piece of electronic equipment, is generally of extremely low magnitude. It is necessary therefore to amplify this signal before work can be performed. This is done by the use of two or more valves connected in certain ways as discussed below.

Reference:

A.P. 1093, Chapter XI, paras. 1, 2, 4 & 5.
6 to 9 (inclusive)
16 to 21 (inclusive)
26 to 31 (")
32 and 74
A.P. 1093, Chapter XII paras. 72 to 76 (inclusive)

Resistance Capacity

Here the signal is supplied to the grid of V_1 which amplifies it so that the anode A is alternating with a greater magnitude than the signal voltage (refer back to Class A operation). It is necessary to pass this alternating voltage to the grid of V_2 which in the case of fig.37 is capable of handling sufficient power to operate a loud speaker. Operation of other devices will be dealt with in Part 2 but the same principles hold good in sound reproduction. Now point A has also a steady D.C. potential applied to it, which prevents us from connecting the grid of V_2 directly to it. The grid of V_2 also must be at some steady bias potential, this is accomplished by connecting it to the bias potential through rg (usually about 1 megohm). The alternating voltage at A can be applied to the grid of V_2* but pass the A.C. The equivalent circuit now becomes as shown in fig.38.

It will be seen that the condenser C and leak resistance rg are in parallel with the load resistance of V_1. For this reason rg must be of

*Insert:- by the condenser C, which will prevent the steady D.C. from being applied to the grid of V_2

.../high value.

high value. Also notice that the alternating voltage applied to the grid of V_2 is less than that developed through the load resistance by the voltage drop across the condenser, which is in series with rg. The condenser C then must offer a low impedance, and therefore be of relatively high capacity. When the frequency of the signal is low, the voltage drop across the condenser increases, so that the voltage developed across rg will be reduced. At high frequencies the capacity effects existing in the valve V_1 also cause a drop in strength of the signal on V_2, due to its capacity being in parallel with the load resistance. These points are of importance if a wide range of frequencies have to be dealt with, as in sound reproduction, but are of minor importance if the signal frequency is fixed, and suitable values chosen for C and rg.

Transformer Coupling

Here the primary of a transformer is connected in series with the anode of V_1 the secondary feeds grid of V_2 fig. 39.

Here the advantage of the transformer ratio is gained, giving an overall increase as compared with resistance-capacity coupling. The equivalent circuit is shown in fig.40. The disadvantages are:

1. The impedance of the transformer varies with frequency so that in the case of sound reproduction, the response is not even to all notes of equal amplitude.

2. The transformer primary is carrying the continous D.C. to V1 so that the transformer iron is not operating at the zero point of the B/H curve, and has to be fairly large to avoid saturation when the anode current of V_1 is increased by the signal going positive.

3. Due to the inductance of the windings there is a considerable phase shift between the signal on the grid of V_1 and that on V_2, which though not of great importance on sound reproduction, is a big disadvantage with many electronic engineering devices.

Resistance-Capacity-Transformer Coupling

To overcome the disadvantage outlined in (2) of Transformer coupling, the circuit shown in fig. 41 may be adopted. The equivalent circuit being shown in fig.42.

Parallel Output Valves

Where the output of one valve is not sufficient to operate the load, then two valves may be connected in parallel as shown in fig. 43. The anode current changes will be twice that of a single valve if the two valves are similar.

Push-Pull Operation

The two output valves are connected as in fig.44, the H.T. positive being connected to the centre tap of the output transformer's primary, while the bias goes to the centre tap on the secondary of the inter-valve transformer.

The steady anode currents to each valve, passing through the output transformer in opposite directions cancel each other's magnetic effect, so that the core flux is zero when no signal is received. This allows a much smaller iron core to be used. When signals are received the grids become alternately positive and negative with respect to the bias potential, so

.../that the

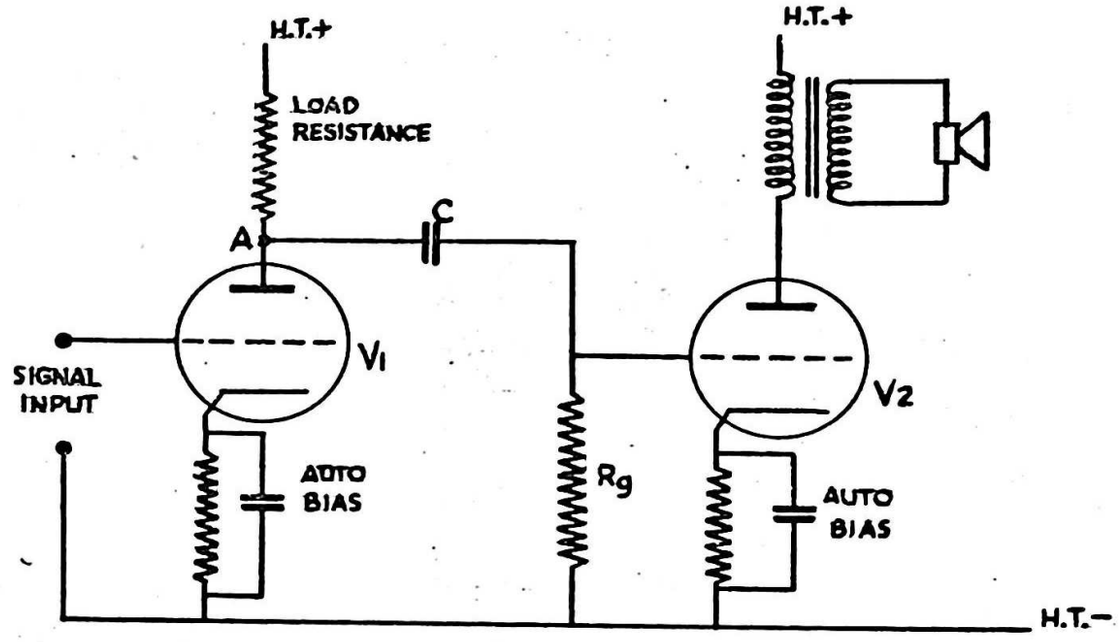

H.T.+
LOAD RESISTANCE
A
C
V1
SIGNAL INPUT
AUTO BIAS
Rg
H.T.+
V2
AUTO BIAS
H.T.-

Fig. 37

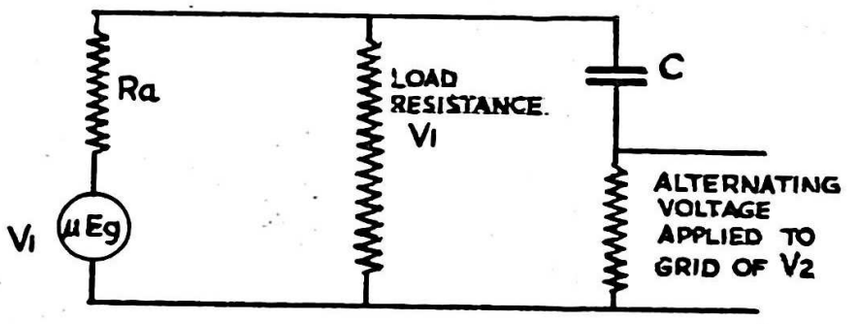

Ra
V1
μEg
LOAD RESISTANCE.
V1
C
ALTERNATING VOLTAGE APPLIED TO GRID OF V2

Fig. 38

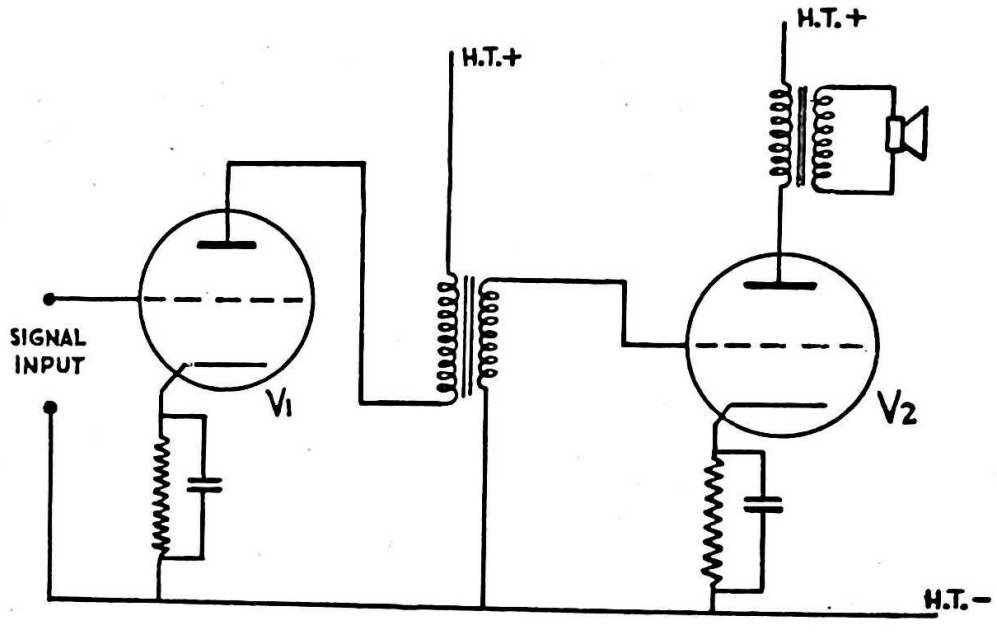


Fig. 39

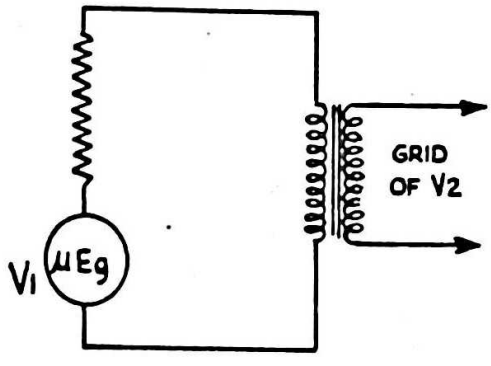


Fig. 40

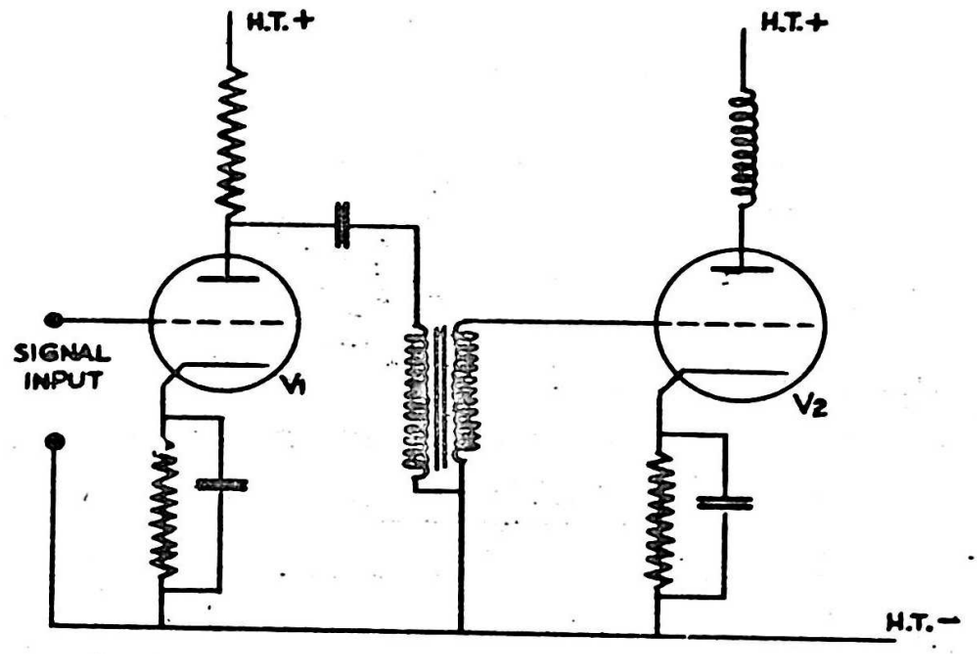


Fig. 41

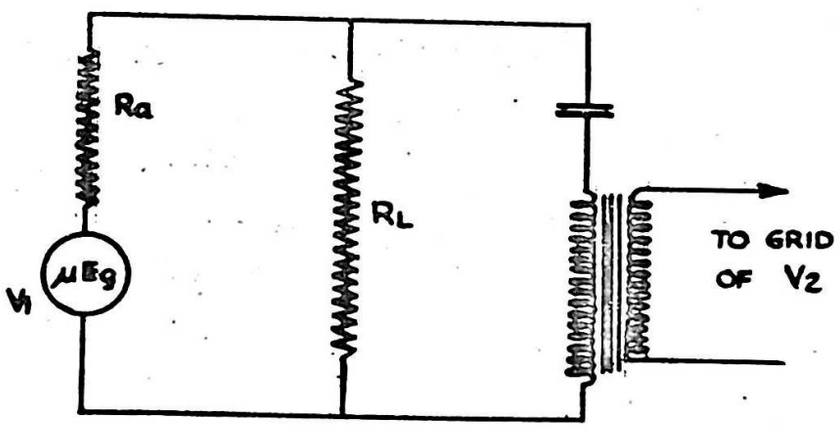


Fig. 42

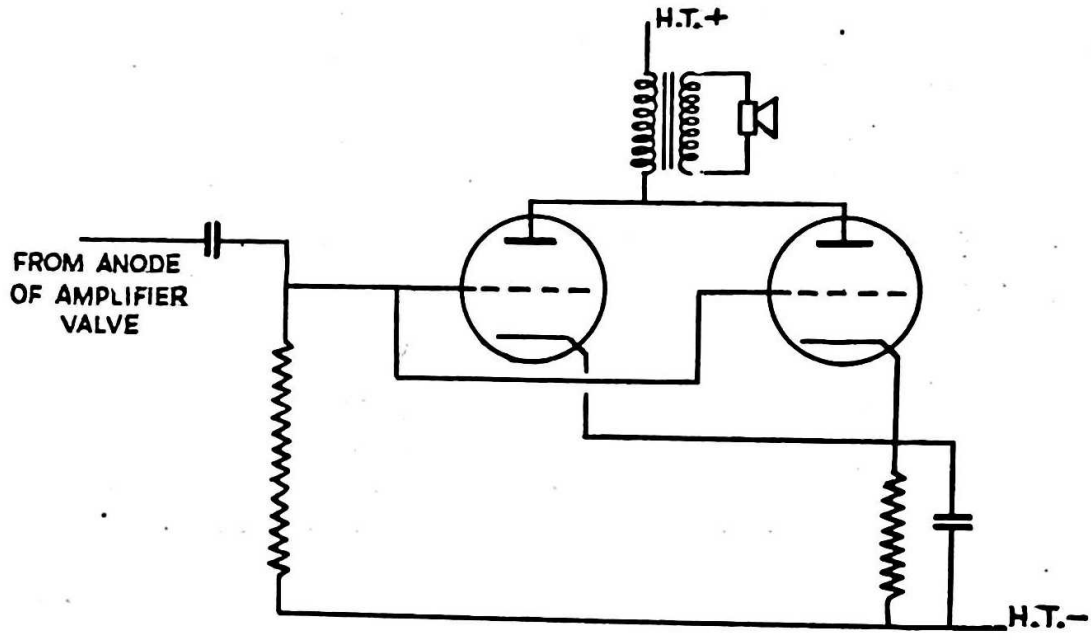

H.T.+
FROM ANODE
OF AMPLIFIER
VALVE
H.T.-

Fig. 43

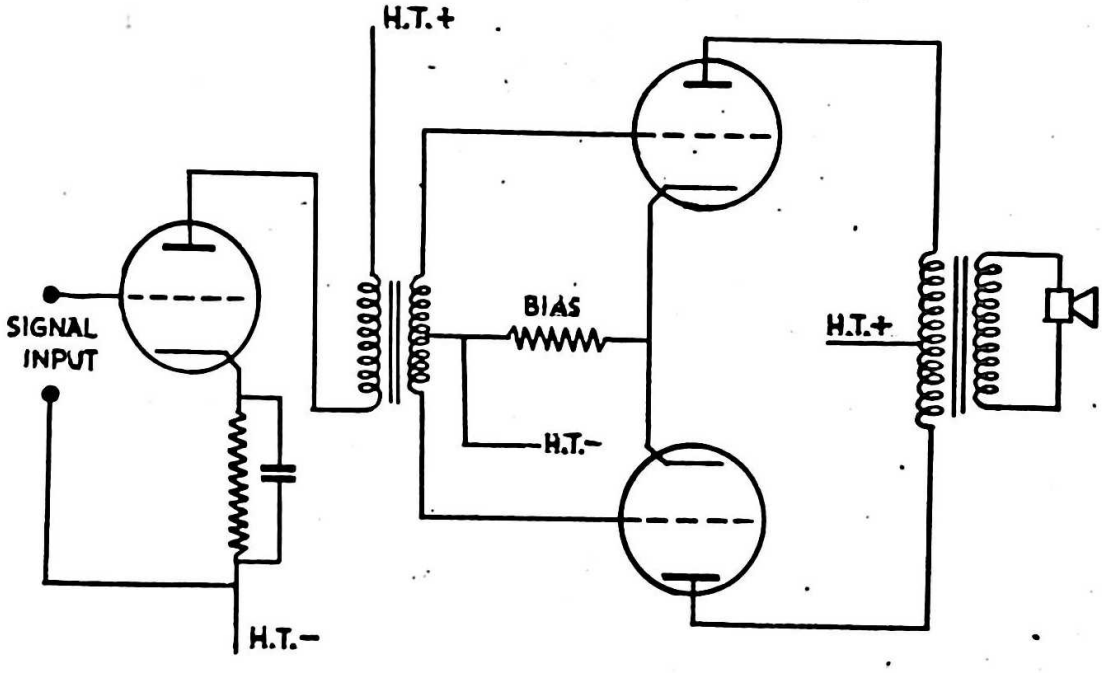

H.T.+
SIGNAL
INPUT
BIAS
H.T.+
H.T.-
H.T.-

Fig. 44

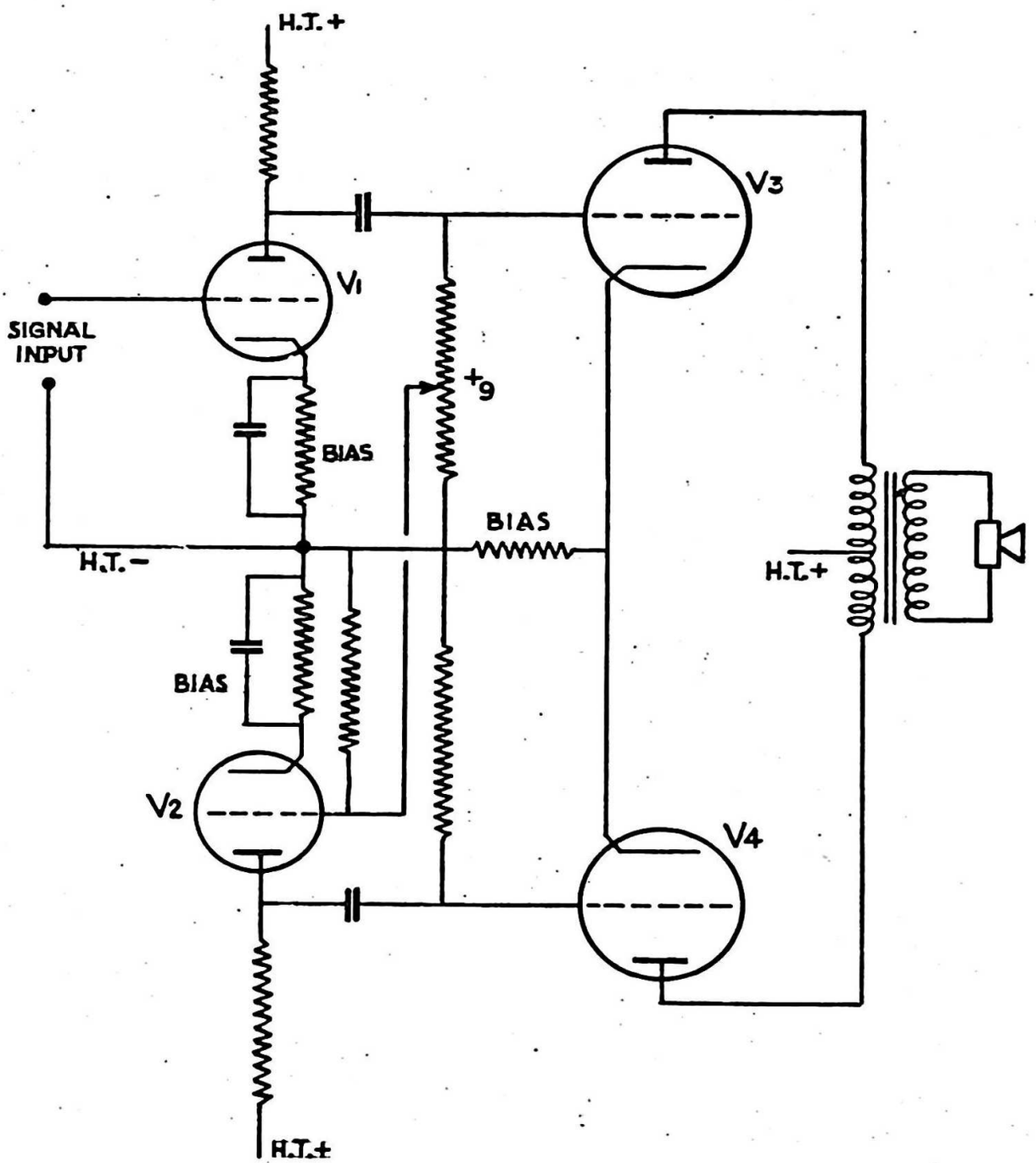


Fig. 45

that the anode current of one valve increases, whilst that of the other decreases. The two halves of the transformer primary winding are now unbalanced and the resultant flux change operates the speaker. It is not necessary now to have a by-pass condenser across the bias resistance as the average current, which is the sum of the two valves remains constant i.e. the increase of anode current in one valve is equal to the decrease of the other.

Quiescent Push-Pull - Q.P.P.

The circuit is similar to that used in normal Push-Pull, but the bias is increased until both valves are near the cut-off point as in Class B operation. The no-signal anode current is now little more than zero. The signal now causes the grid of one valve to become positive above cut-off potential, so allowing anode current through its half of the transformer, meanwhile the other grid will be negative below cut-off, so that its anode current is nil. The next half cycle finds conditions reversed, the valves operating their respective halves of the transformer alternatively.

"Para-Phase" Feed for Push-Pull

This is a method adopted when it is desired to operate push-pull valves by resistance-capacity instead of transformer coupling. The circuit is shown in fig.45. To operate the push-pull system, the grid voltages must be in opposite phase, i.e. as one goes positive the other must go negative. The anode of V_1 applies the magnified signal to the grid of V_3 of the push-pull pair. Now this amplified signal is 180 degrees out of phase with the original signal (refer to Class A Operation). The grid resistance rg of V_3 is tapped at point where the alternating voltage is of equal magnitude to the imput on the grid of V_1. This is now connected to the grid of V_2, which is connected to the grid of V_4 by Res-capacity coupling, V_2 again reversing the phase so that V_4 is supplied with a signal of equal magnitude to V_3 but of opposite phase.

De-Coupling

It has been considered up to the present that the alternating components of the anode currents of the various valves, flow through the D.C. battery or power supply, without any opposition, as though the supply battery had no internal resistance. This is not so, and a considerable alternating voltage can be developed across the D.C. supply, especially by the alternating currents of the output valves. Consider the circuit fig.46 where the internal resistance has been drawn outside the battery. Fig.47 shows the equivalent circuit.

From this it will be noticed that the anode current changes of V_2, cause an alternating voltage to be applied to the anode of V_1, and also back to its own grid through the coupling condenser. In this case the feed-back as it is called is negative, since an increase of anode current of V_2 (caused by a positive signal on its grid) will cause an increased voltage drop through the internal resistance of the battery, resulting in a drop in potential to the grid of V_2. If three valves had been connected by resistance capacity coupling, the negative feed-back would be fed to the middle valve of the series, which would magnify it and reverse its phase, converting it into a positive feed-back on the last valve. This sometimes accounts for an amplifier building up an

.../oscillation.

This defect is overcome by de-coupling as shown in fig.48. The equivalent circuit fig. 49 shows that the de-coupling condenser is in parallel with th supply to V_1, and the alternating voltage developed through the internal resistance will be mostly expended through the resistance R.D. so that the voltage fed back to V_2 is negligible.

Reference:

A.P. 1093. Chapter XI, paras 1, 2 4 & 5.
6 to 9 (inclusive)
16 to 21 "
26 to 31 "
32 and 74
A.P. 1093. Chapter XII, paras 72 to 76 (inclusive)

.....

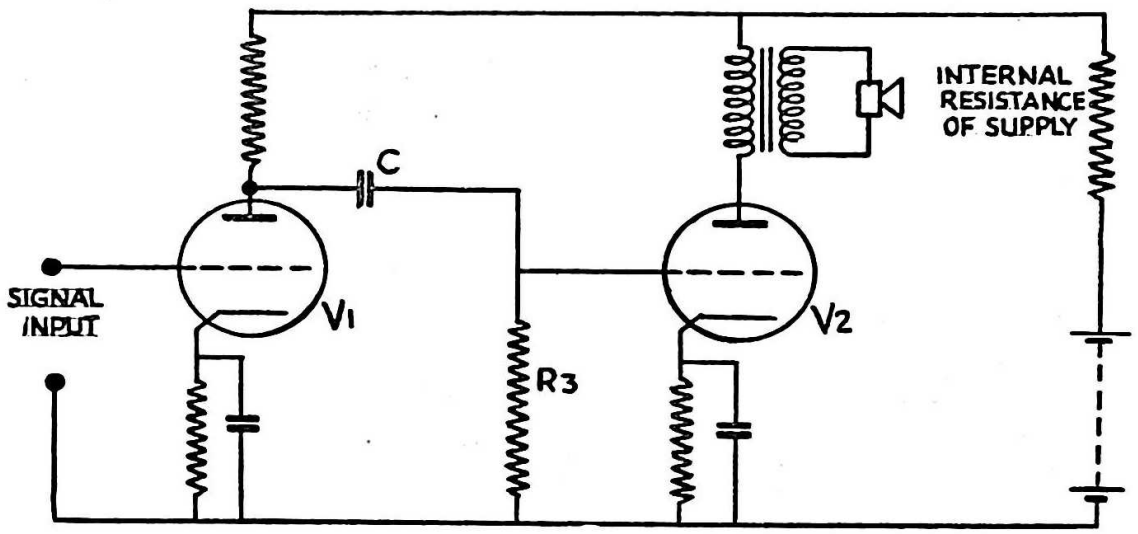

INTERNAL
RESISTANCE
OF SUPPLY
C
SIGNAL
INPUT
V1
V2
R3

Fig. 46

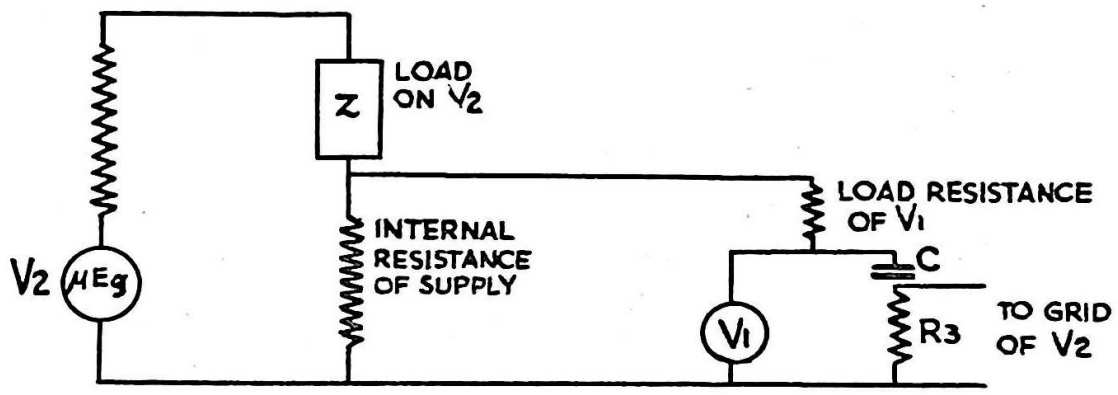

Z
LOAD
ON V2
LOAD RESISTANCE
OF V1
INTERNAL
RESISTANCE
OF SUPPLY
C
V2
μEg
V1
R3
TO GRID
OF V2

Fig. 47

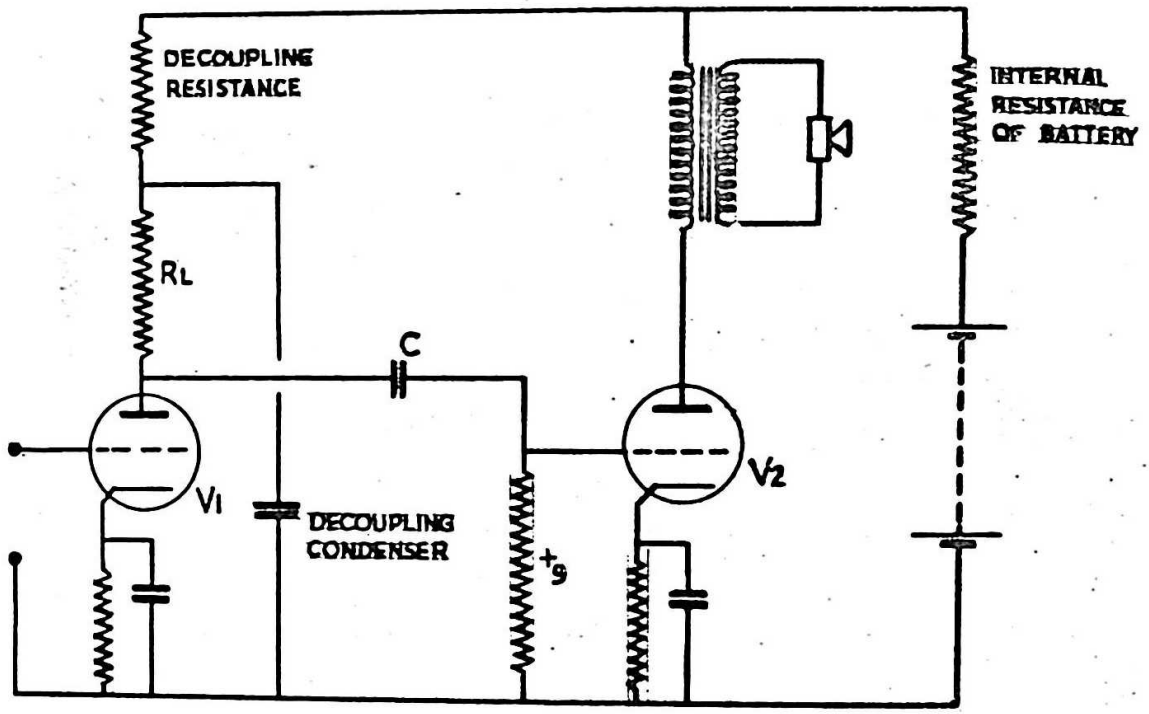

DECOUPLING
RESISTANCE
RL
C
V1
DECOUPLING
CONDENSER
+g
V2
INTERNAL
RESISTANCE
OF BATTERY

Fig. 48

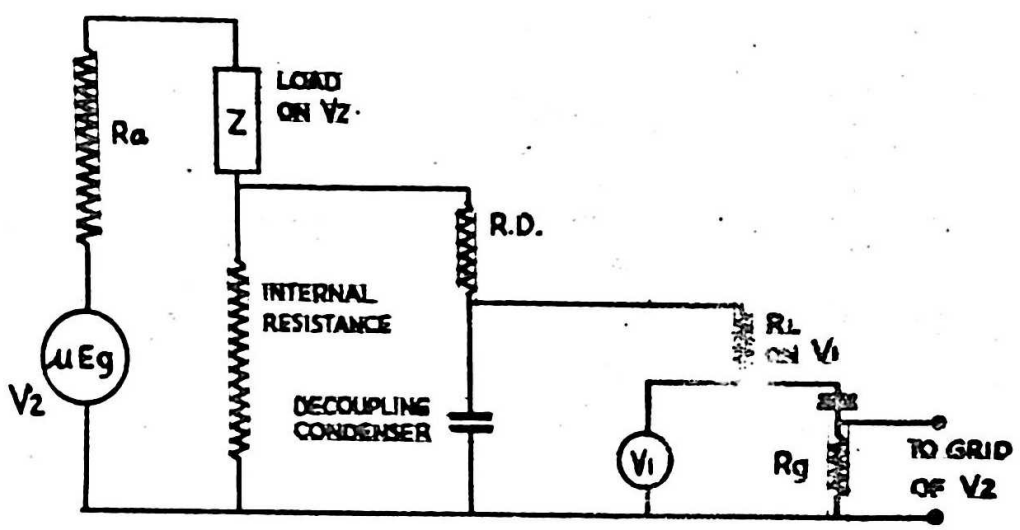

Ra
Z
LOAD
ON V2
R.D.
INTERNAL
RESISTANCE
μEg
V2
DECOUPLING
CONDENSER
RL
V1
Rg
TO GRID
OF V2

Fig. 49

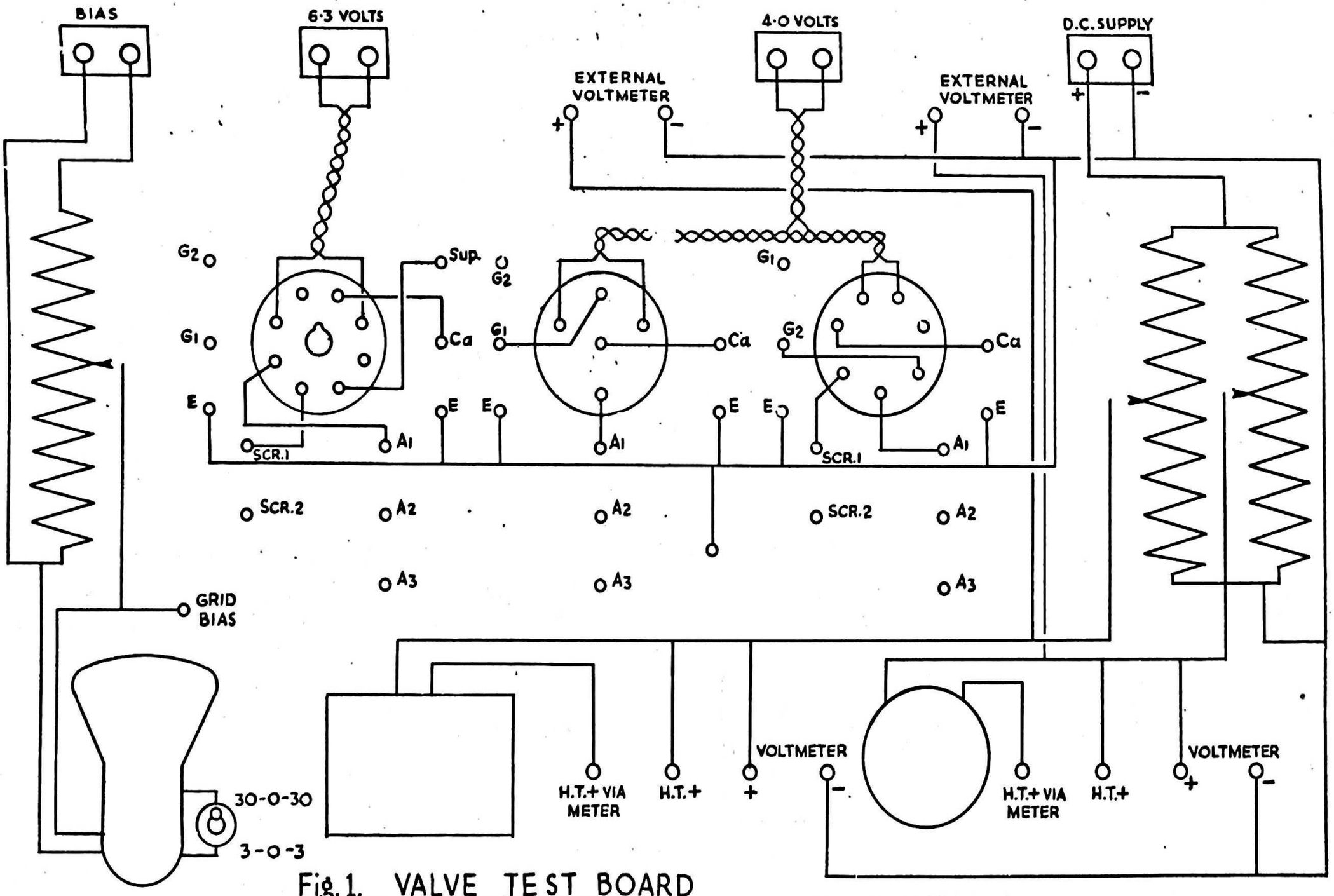


Fig. 1. VALVE TEST BOARD

ELECTRICAL & INSTRUMENT SECTION

HENLOW DIVISION, R.A.F. TECHNICAL COLLEGE

INSTRUCTIONS ON LABORATORY WORK AND EXPERIMENTS

Instrument Precis No.2

General Notes on the Laboratory Work

1. Students should remove all components and wiring from the test boards at the end of each laboratory period. These should be placed carefully and neatly inside the box provided under each bench space. The list of components in each box will be checked at the end of the period. All plugs should be disconnected and all switches turned off.

2. Instructions herein for each experiment should be studied carefully before commencment. If in doubt about the connections or method etc. ASK THE INSTRUCTOR TO CHECK before switching on.

3. Experimental curves obtained in the laboratory will be referred to in the lectures and if time does not permit them to be neatly done in the course of the period, they are to be completed at the earliest opportunity in the Student's own time.

4. Before the end of the course the senior Electrical Instructor may require experimental results to be handed in for checking.

The Valve Test Board

Fig.1 shows a schematic layout and wiring diagram of the Valve Test Board. This board will be used in most of the experiments. It has been prepared to facilitate quick and easy connection for valve characteristics, etc., and also for each check on the correct circuit. The diagram of the board is self explanatory. It should be noted that there are two circuits marked "Voltage Circuit No.1" and "Voltage Circuit No.2". The appropriate potentiometer or regulator allows any voltage to be impressed between "H.T+" or "H.T. + via meter" and any"earth" terminal from 0 to 220 volts D.C. on either circuit. For each circuit there are alternative positions at the front and rear of the board for an external voltmeter.

The bias circuit is so connected that when the slider is at the rear end of the potentiometer a negative bias is obtained and at the rear end, a positive bias, between the terminal "Grid Bias" and any terminal marked "E".

The valve holders on the board are 5 pin Britis 7 pin British and International octal. The pin connections are brough ut to terminals marked according to the electrode to which they are connected in the valves used. It must be noted that these are not standard for all valves. The basing data for all service valves is given in A.P. 1186, Vol.1, Section 8.

Certain "dummy" terminals have been inc ated for ease in connecting component parts into the circuit. These component parts such as Resistances, Condensers, Potentiometers, Chocks, etc., together with the Valves and connecting leads will be found in the box under each bench space.

In general, two Students will work together on each board.

Experiment 1

Aim and object : To obtain the characteristics curve of a Diode Valve.

.../Apparatus

Apparatus Required : The Valve Test Board.
1 Voltmeter, 0-300 volts.
Valve - V.R. 37 - (Triode, indirectly heated, 4 volt heater).

Connecting leads.

Diagram of Connections : See figure 2.

Procedure : Insert the V.R. 37 into the 5-pin valve holder. Connect terminal "H.T. + via meter" to "A", this places the voltage from the supply on to the anode of the valve and an ammeter in the anode circuit reads the anode current flowing through the valve.

Connect a voltmeter, (0-300 volts) between the terminals marked "External Voltmeter, + and -", of the appropriate voltage circuit used.

Connect the 4v heater plug into the 4v A.C. supply (The heater should warm up and begin to glow).

Connect up the main supply plug to the 5 amp. switch socket.

If you are satisfied that the connections are correct, switch on the supply.

N.B. The two voltage supply regulators on the board should be at all times before beginning experiment in the position so that the voltmeter reads zero when the supply is switched on. i.e. the slider should be at the near end of the potentiometer.

Increase the anode voltage (Ea) in steps of 10 volts from zero until the anode current (Ia) reach 7.5 m/a. THIS FIGURE FOR Ia (i.e. 7.5 m/a) MUST ON NO ACCOUNT BE EXCEEDED WITH THIS VALVE.

Tabulate your results as below and plot your characteristic curve.

Ea Volts	Ia Milliamperes.

NOTE: In class this characteristic will be discussed and the anode resistance (Ra) will be calculated by the Student from his curve.

Experiment 2

Aim and Object : To obtain the Anode current - Anode Voltage (IaEa) characteristic of a triode valve with fixed values of Grid Bias.

Apparatus Required: As for experiment 1.

Diagram of Connections See fig. 3.

Procedure Connect up the board as in fig.3. The grid supply is arranged so that positive and negative voltages can be obtained and read on the 30-0-30, 3-0-3 voltmeter. This voltmeter should be kept on the 3-0-3 range throughout this experiment.

.../Set the

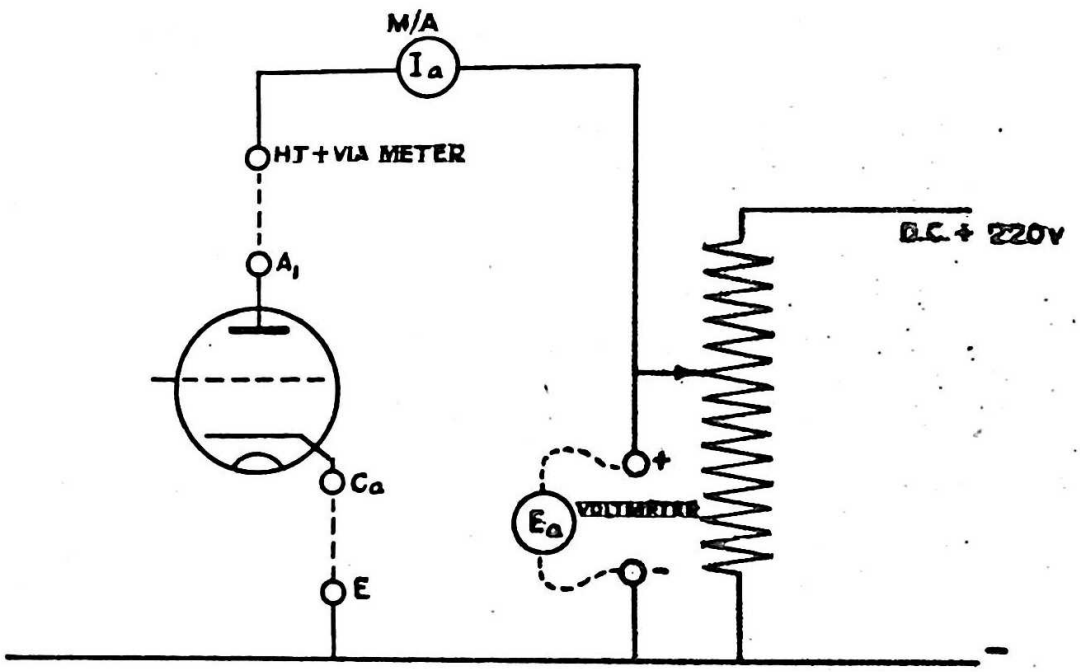

M/A
I_a
HT + VIA METER
A_1
D.C. + 220V
C_a
+
E_a
VOLTMETER
-
E
-

Fig. 2.

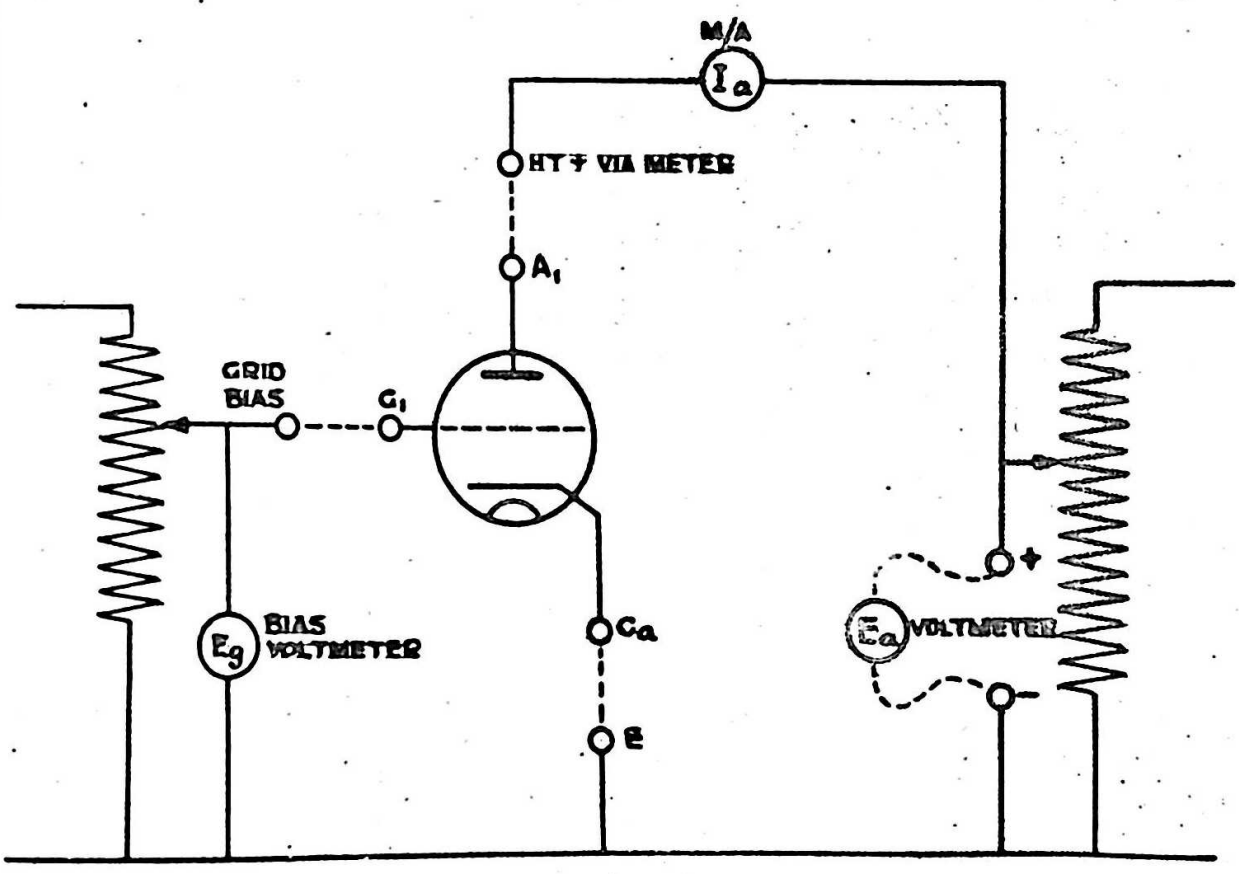

M/A
I_a
HT + VIA METER
A_1
GRID BIAS
G_1
E_g
BIAS VOLTMETER
C_a
E
+
E_a
VOLTMETER
-

Fig. 3.

Set the grid voltage at the following values, +1, 0, -1, -2, -3, and in each case increase Ea from zero in steps of 10 volts until Ia reaches 7.5 m/a. DO NOT EXCEED THIS ANODE CURRENT

Tabulate your results as below and plot out your Ia Ea characteristic curves.

Ea	Ia for given values of Eg				
	+1	0	-1	-2	-3

NOTE: In class, Ra, gm and μ will be deduced from your results and it will be shown how the Static and dynamic Anode Current - Grid Voltage (Ia Eg) characteristics can be obtained from your Ia Ea characteristic.

Experiment 3

Aim and Object : to determine:
(a) The static Ia Eg characteristics.
(b) The dynamic Ia Eg characteristics of a Triode valve.

Apparatus Required : As in Experiment 1 and in addition :
1. Resistance 33,000 ohms.
1. Resistance 20,000 ohms.

Diagram of Connections : See fig.3.

Procedure : (a) Static Ia Eg Characteristic

Connect up the circuit as in fig.3.

With Ea fixed at the following values, 60v, 100v, 140v, 180v, vary Eg in steps of 0.5 volts to obtain readings of Ia from zero to 7.5 m/a for each setting of Ea.

NOTE : The grid bias voltmeter should be kept on the 30-0-30 range throughout the experiment.

Tabulate your results as below and plot your characteristics.

Eg	Ia for given value of Ea			
	60v	100v	140v	180v

(b) Dynamic Ia Eg. Characteristic
Disconnect the lead between "H.T. + via meter" and "A".

.../Connect

Connect "H.T. + via meter" to "A2".
Connect a resistance of 20,000 ohms between "A" and "A2"
Repeat the procedure of 3(a) with the Resistance Load (R_L) in the Anode Circuit.
If time permits, replace the 20,000 ohms resistance by a resistance of 33,000 ohms, and repeat the experiment. Tabulate your results as below and plot your characteristics.

	Ia with 33,000 ohms. load and given Ea				Ia with 20,000 ohms load and given E.			
Eg	60v	100v	140v	180v	60v	100v	140v	180v

NOTE: In class Ra, gm and μ will be calculated from the results of your static characteristic. The meaning and use of Class "A" and "B" operation will be dealt with on a Dynamic Characteristic.

With reference to curves of experiments 2 and 3, the limitations of the load line will be dealt with and the stage gain and power output derived.

Experiment 4

Aim and Object : To determine the Anode Current - Anode Voltage Characteristic and the Screen Current - Anode Voltage (I_{scr}EA) characteristic of a Tetrode valve.

Apparatus required : Valve Test Board
Valve V.R. 56 (Pentode) 6.3v heater..
2. Voltmeters 0-300v.
Connecting leads.

Diagram of Connections : See fig.4.

Procedure.

Connect up the circuit as in fig.4.

The Suppressor Grid and the Screen Grid are linked together so that the valve behaves as a Tetrode and are fed with H.T. + voltage from the Second "Voltage Circuit".

Set the Screen Voltage (E_{scr}) at 80v.

With the grid voltage set at the following values, -1.0, -0.8, -0.6 vary Ea from zero to 80 volts in steps of 4v and from 80v upwards in steps of 20v. for each setting of Eg. Read both Ia and the Screen current (I_{scr}) at each setting of Ea.

Tabulate your results as below:

Ea	Ia and I_{scr} with given Eg - E_{scr} = 80v					
	Eg = -1.0		Eg = -0.8		Eg = -0.6	
	Ia	I_{scr}	Ia	I_{scr}	Ia	I_{scr}

.../Plot

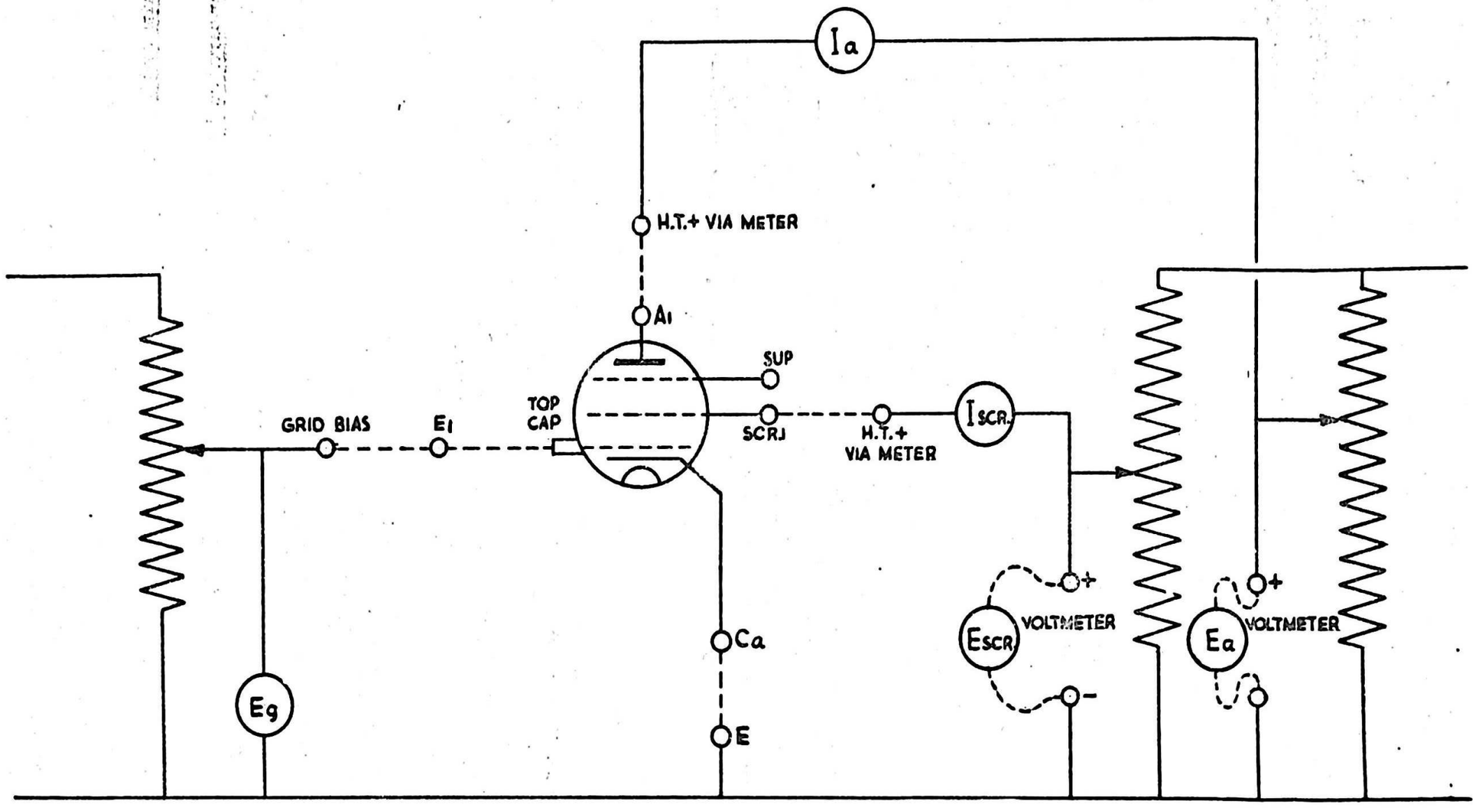

Ia
H.T.+ VIA METER
A1
SUP
SCRJ
TOP CAP
GRID BIAS
E1
H.T.+ VIA METER
ISCR.
Ca
E
Eg
ESCR
VOLTMETER
Ea
VOLTMETER
+
-
+

Fig. 4

Plot on the same piece of graph paper your Ia Ea curves and your I_{scr} Ea curves. NOTE. Ra, gm and μ for this type of valve and the limitations of the load line will be dealt with in class.

Experiment 5

Aim and Object : To determine the Ia Ea and I_{scr} Ea curves of a pentode valve.

Apparatus Required : As for Experiment 4.

Diagram of circuit : The same as fig. 4 with the following modifications :-
Remove the connection between terminal "Sup" and "Scr 1".
Connect "Sup" to "E".
Connect "Scr 1" to H.T. + via meter".

Procedure :

Connect up as stated above.
Set E_{SCR} at 80v. The suppressor grid will be at "earth" or "cathode" potential.
With the Eg set at -0.6, -0.8, -1.0 vary Ea from zero to 60v in steps of 4v and from 60v upwards in steps of 20v for each setting of Eg. Read Ia and I_{scr} for each setting of Ea.

Tabulate your results as below and plot the Ia Ea and I_{scr} Ea characteristics.

Ia & I_{scr} with E_{scr} = 80v and given values of Eg							
Eg = -0.4		Eg -0.6		Eg -0.8		Eg = -1.0	
Ea Ia	I_{scr}	Ia	I_{scr}	Ia	I_{scr}	Ia	I_{scr}

Experiment 6

Aim and Object To examine the effect of resistance in (a) the grid and (b) the cathode circuits of a Triode valve.

Apparatus Required : As for Experiment 1, and in addition:

1 Resistance	1 megohm
1 Resistance	1,000 ohms.
1 Resistance	500 ohms.

Diagram of Circuit : See fig.3.

Procedure

(a) Resistance in the Grid circuit

Disconnect lead between "Grid Bias" and G_1.
Reconnect it between "Grid Bias" and G_2
Connect resistance of 1 megohm between "G_1" and G_2"

With Ea set at 60v and 80v, vary Eg in steps of 0.5 for each setting of Ea. Read Ia for each setting of Eg. Ia MUST NOT EXCEED 7.5 m/a.

Tabulate your results as shown below.

Ia for given values of Ea		
Eg	60v	80v

(b) Resistance in Cathode Circuit

Remove wiring of Experiment 6 (a) and rewire as per fig.3.
Disconnect lead between "Ca" and "E".
Replace by a resistance of 1,000 ohms.
With Ea at 60v and 8-v vary Eg is steps of 0.5v for each setting of Ea. Read Ia for each setting of Eg.

Now replace resistance of 1,000 ohms between "Ca" and "E" by a resistance of 500 ohms and repeat the reading taken above.

Tabulate your results as below and draw curves for Experiment 6(a) and (b) on the same piece of graph paper.

	Ia for given Ea and R Cathode			
	1,000 ohms		500 ohms	
Eg	80v	60v	80v	60v

Experiments with the Cathode Ray Tube

The next series of experiments are given to examine valve operation visually with the aid of the Cathode Ray Tube (C.R.T.). In general there will be one C.R.T. between two of the Valve Test Boards. It should be understood that when using the C.R.T. no good results will be obtained if more than one person tries to adjust more than one control knob at once. Initially for the first experiments and until some idea of the action of the C.R.T. controls has been gained, they are set so that it will only be necessary to adjust the control marked "Velocity" on the Cossor Double Beam C.R.T. or that marked "Fine" on the Ultrascope C.R.T.

At NO TIME must the spot be left in a stationary position on the screen, as this rapidly causes burning and failure of the Screen. The "Brilliancy" control should only be turned up until a readable trace is seen. Excessive brilliancy also causes damage to the screen of a C.R.T.

When any alteration of wiring is necessary ALWAYS SWITCH OFF THE H.T. + Supply

In all these experiments, a 9 henry choke is required in the anode circuit and a 10 mfd. condenser between anode supply and "earth", to smooth out the ripple existing in the D.C. mains supply. Thus, before beginning any one of the next ten experiments make the following connections:

Between "A2" and "A3" connect a 9 henry choke.
Between "A2" and "E" connect a 10 mfd. condenser.

.../In these

In these experiments the signal is obtained from the "Signal Input Transformer" located in the top of the bench. Two supplies of 3 volts peak value are taken from each of these transformers to the boards on either side of the bench. The value of the signal can be varied by the potentiometer calibrated in 11 steps.

The experiments are designed so that use can be made of the characteristic curves contained in the previous experiments. It is, therefore, desirable to refer to those when doing the following experiments as the conditions of operation can be earily seen.

Experiment 7

Aim and Object — To examine the output of a triode valve working under conditions of "Class A" operation.

Apparatus Required

Valve Test Board.
Signal Input Transformer.
Valve - V.R. 37, Triode, indirectly heated 4v heater.
1 choke, 9 henry.
1 condenser, 10 mfd.
1 Resistance, 20,000 ohms.
1 Voltmeter, 0-300 volts.
Cathode Ray Tube.
Connecting leads.

Diagram of Connections

Procedure

Connect the circuit up as shown in fig.5.
"A1" being connected to the "Y" plate of the C.R.T. (i.e. "Y_1" terminal on the Cossor Tube, "Y" terminal on the Ultrascope).
"E" is connected to the common "earth" terminal of the C.R.T. (also marked "E").
Adjust Ea to 100v, 180v and 220v. In each case check the value of the steady D.C. bias you have to apply from the Grid Voltage potentiometer and the maximum signal amplitude, to obtain a pure sine wave (i.e. undistorted output) on the C.R.T. Measure the amplitude output with signals of 1, 2 and 3v. The valve should be then working under conditions of "Class A" operation i.e. on the straight portion of the dynamic characteristic.

NOTE: That the m/a will read the same with zero signal or maximum signal when working under these conditions of "Class A" operation.

Experiment 8

Aim and Object : To examine the output of a triode valve, working under condition of "Class B" operation

Apparatus Required : As in Experiment

Diagram of Connections : See fig.5 as for Experiment 7.

Procedure

Using the same circuit as in Experiment 7, and the same anode voltage (i.e. 100v, 180v, 220v). Bias the valve back to its "cut-off" point. (This can be determined from the dynamic characteristic obtained in Experiment 3).

Check the output wave form as seen on the C.R.T. as being "Class B" operation.

.../NOTE

NOTE Under these conditions it will be seen that as the signal increases the value of anode current increases also. (This is the reason why automatic bias cannot be used when working under conditions of "Class B" operation).

Experiment 9

Aim and Object : To compare the output obtained on "Class A" operation with differing resistance loads in the Anode Circuit.

Apparatus Required : As for Experiment 7, and in addition:
1 Resistance, 33,000 ohms.

Diagram of Connections : See fig.5 as for Experiment 7.

Procedure

Disconnect the 20,000 ohm load and replace by one of 33,000 ohms.

Carry out the same procedure as in experiment 7, noting the difference in the output amplitude with input signals of 1, 2 and 3 volts. peak value.

Experiment 10

Aim and Object : To see the effect of resistance in the cathode circuit, on the output of a triode valve.

Apparatus Required : As for Experiment 9, and in addition:
1 Resistance 1,000 ohms.
1 Resistance 500 ohms.

Diagram of Connections : See fig.5 with the following modifications:
Replace 20,000 ohm load by one of 33,000 ohms. Remove connection between "C_a" and "E". Connect a Resistance of 1,000 ohms between "Ca" and "E".
Remove connection between "G_1" and "Grid Bias". Connect signal between "G_1" to "E". (This removes the steady grid supply from the Grid Bias potentiometer.)

Procedure

With the same Ea values as in the three previous experiments (i.e. 100v, 180, 220v). Note and compare the amplitudes of the voltage output on the C.R.T. with input signals of 1, 2 and 3v peak value, comparing your results with those obtained in experiment 9.

Replace the 1,000 ohm resistance by one of 500 ohms and repeat the experiment.

Experiment 11

Aim and Object : To see the effect of the "By-Pass" condenser in Automatic Grid Biasing.

Apparatus Required : As in Experiment 10, and in additions:
1 Condenser of 10 mfd. or 8 mfd.

Diagram of Connections : As for Experiment 10.

.../Procedure

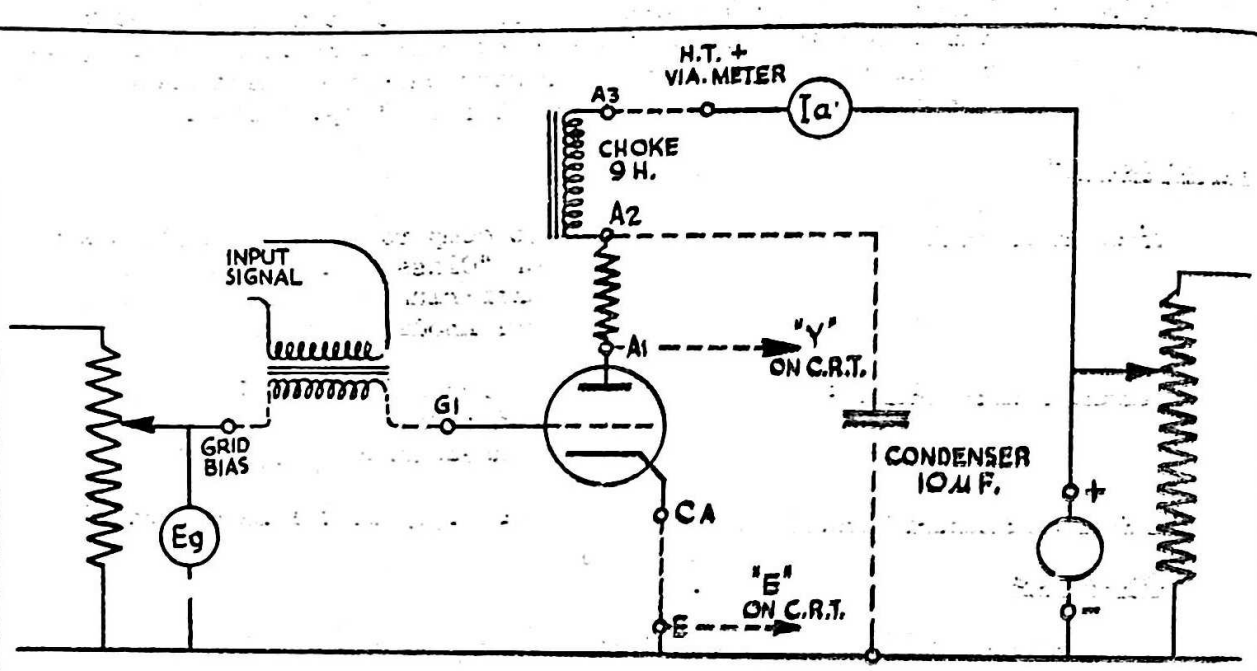


Fig. 5

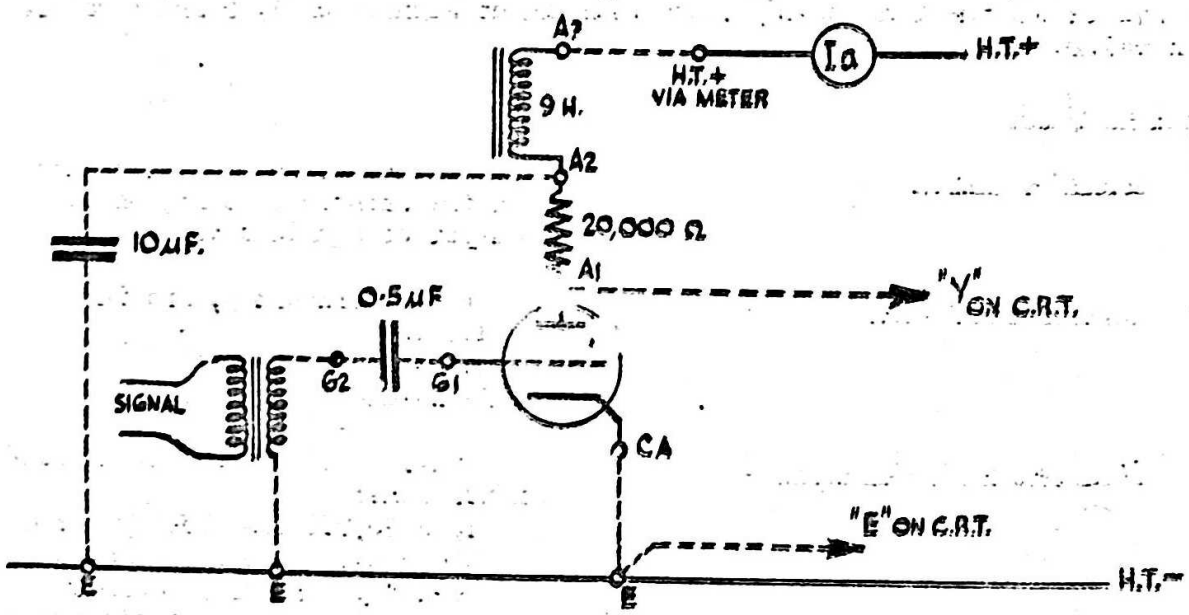


Fig. 6

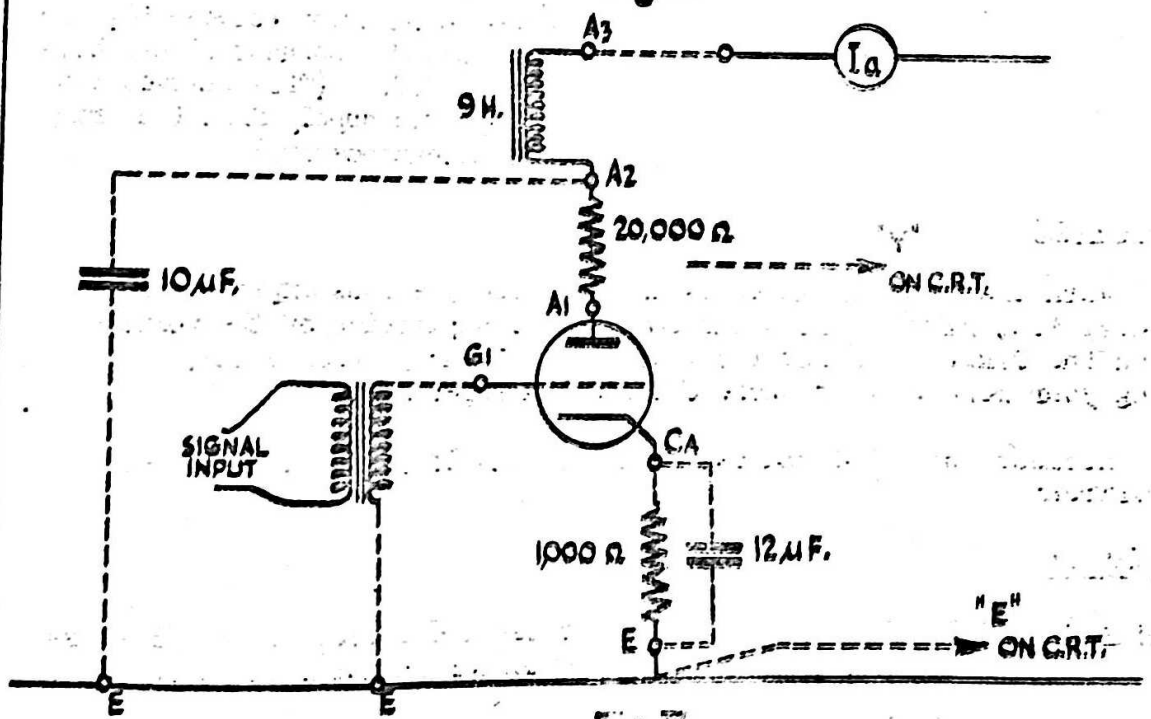


Fig. 7

Procedure

Connect this condenser between "Ca" and "E" so that it will be in parallel with the cathode resistor.

Using the 1,000 ohm resistance between "Ca" and "E" and then the 500 ohm resistance, note the magnitude of the trace now approaches that obtained in Experiment 9, but that the average Ia is different for the two Resistances.

Experiment 12

Aim and Object : To show the effect of a condenser in the grid circuit of a triode valve.

Apparatus Required : Valve Test Board. Signal input transformer.
Valve V.R.37. (Triode, I.H.4v.Heater).
C.R.T.
1 Resistance 20,000 ohms.
1 Condenser 10 mfd.
1 Condenser 0.5 mfd.
1 Choke 9 henries.
Connecting leads. Voltmeter 0-300v.

Diagram of Connections See fig.6.

Procedure

Connect up as shown in fig.6. Ensure that the signal is at zero and the condenser (0.5 mfd.) is discharged fully. Apply a H.T. + potential of 150v. Make a note of the Anode Current.

Now increase the signal value slowly. Note the Anode current as the signal increases (it should decrease). Notice that the trace on the C.R.T. shows signs of rectification taken place on the maximum signal input.

Reduce your signal to zero and note that the milliammeter maintains the low value until the condenser is discharged.

Alter the C.R.T. switch from A.C. to D.C. (on the cossor tube, there is no switch provided on the Ultrascope). Repeat above test and note that the x-axes of the trace on the C.R.T. moves when the signal is applied.

Experiment 13

Aim and Object : To see the effect of the "Leak Resistance" in Grid Leak Detection.

Apparatus Required : As for Experiment 12, and in addition:
1 Resistance 0.5 megohms.

Diagram of Connections : See fig.6 with the following modification:
Place resistance 0.5 megohms between "G_1" and "G_2" so that it is in parallel with the existing 0.5 mfd. condenser.

Procedure

Repeat the procedure of Experiment 12, noting that now Ia decreases when the signal increases and increases when the signal decreases.

Now remove the 0.5 megohm resistance from its position and place between "G_1" and "E". Repeat the procedure. This new position should make no difference to the results obtained.

Experiment 14:

Aim and Object : To show the effect of resistance-capacity coupling.

Apparatus Required : Valve Test Board, Signal input transformer.

C.R.T.
9 Henry Choke.
1 condenser 10 mfd.
1 condenser 12 mfd.
1 condenser 0.1 mfd.
1 condenser 0.01 mfd.
1 resistance 0.5 megohms
1 resistance 33,000 ohms
1 resistance 20,000 ohms
1 resistance 1,000 ohms
Connecting Leads. Voltmeter 0-300v.

Diagram of Connections : See fig.7.

Procedure

Connect up as shown in Fig.7. Apply 200v. H.T. + potential. Note the amplitude of the trace for 1, 2 and 3v. signal input.

Connect a condenser of 0.1 mfd. between "A_1" and any "Dummy terminal" on the board (denoted from now on as "D") which has no existing wiring.

Connect 0.5 megohm Resistance between "D" and "E".

Apply the signal again and note the amplitudes (Are they altered)?

Remove the connection from "A_1" and "Y" plate of C.R.T. and reconnect between "D" and "Y" plate of C.R.T.

Compare the amplitudes now with those obtained at "A_1".

Repeat the procedure above (i.e. "Y" plate of C.R.T. on first "A_1" and then "D") with the following connections:

(i) 0.01 mfd. condenser between "A_1" and "D" in place of the 0.1 mfd condenser.

(ii) 33,000 ohm resistance between "D" and "E" in place of the 0.5 megohm resistance.

(iii) 0.1 mfd. condenser between "A_1" and "D" and 33,000 ohm resistance between "D" and "E".

Which of these connections causes the least change in:

(a) the amplitude of the trace at "A_1"?

(b) the amplitude of the trace at "D"?

Experiment 15

Aim and Object : To examine "phase-shift" in resistance-capacity coupling.

Apparatus required : As in Experiment 14.

Diagram of Connections : See fig.7.

.../Procedure

Procedure

Make the connections as shown in Fig.7.

Connect "A" to "Y" plate of the C.R.T.

Connect "D" to X plate of the C.R.T.

Switch off C.R.T. time base.

"E" (H.T-) should be connected to "E" of C.R.T.

Note the shape of the trace on C.R.T. with the various connections of 0.1 mfd. and 0.01 mfd. condensers and 0.5 megohms and 33,000 ohms resistances connected as in Experiment 14 above.

Note which of these approaches nearest to a straight line trace on the C.R.T. at 45° to the horizontal.

Experiment 16

Aim and Object : To plot the characteristics of a Beam Tetrode Valve.

Apparatus Required : Valve Test Board.
Valve V.T. 75A (4v heater) Top cap anode.
2 voltmeters 0-300v.
Connecting leads.

Diagram of Connections : See Fig.8.

Procedure (i) Connect up the circuit as shown in Fig.8
Set the screen potential at 220v.

With Eg at -14v, -17v, and -20v, vary Ea from zero in steps of 4v to the top of the "knee" of the characteristic and thence in 20v steps to 220v in each case.

Note Ia and I_{scr} for each setting of Ea.

Negative bias must NOT be less than -14 volts.

(ii) Repeat the above procedure with:

E_{scr} = 100v.
Eg = -4, -7 and -10v.

Tabulate your results as below and plot your characteristics.

Ea	Ia with given screen and grid volts					
	E_{scr} = 200v			E_{scr} = 100v		
	Eg - 14	Eg - 17	Eg-20	Eg-4	Eg-7	Eg-10

.../Experiment 17.

Experiment 17

LABORATORY TEST

This test has been set to see whether the principles of experiments so far used in the laboratory have been fully understood and whether the Student can successfully test a valve from first principles himself. The results and curves will be collected and checked and will form part of the final assessment.

Aim and Object : To determine the characteristics of a V.T. 75A used as a triode.

Apparatus Required :
Valve Test Board.
Valve V.T. 75A (4v heater) top cap anode.
1 Voltmeter 0-300v.
Connecting leads.

Diagram of Connections : As you require - show your connections with your answer.

Results Required

(i) (a) The anode resistance (Ra)

(b) The mutual conductance (gm)

(c) The Amplification Factor (u)

(ii) Show on your graph a load of 4,700 ohms at 200v H.T. + supply.

(iii) Find graphically the stage gain.

Experiment 18

Aim and Object : To study the operation of a V.T. 75A on the C.R.T.

Apparatus Required :
Valve Test Board.
2 voltmeter 0-300v.
Valve V.T. 75A (4v heater) top cap anode.
C.R.T.
Signal input transformer.
1 Choke 9 henries.
1 Condenser 10 mfd.
1 Condenser 8 mfd.
1 Resistance 4,700 ohms.
1 Transformer (Primary winding to be used as choke in screen smoothing circuit).

Diagram of Connections : See fig.9.

Procedure : Connect up circuit as shown in fig.9.

(i) Check Bias voltages for Class A and B operation. For class A operation Eg should be about -10v. Note the amplitude of trace 1, 2 and 3v. signal input. Vary the screen voltages.

Note how distortion occurs at low values of Ea.
Disconnect screen smoothing condenser between "Scr1" and "E" (8 mfd) and note the effect on the C.R.T. trace).

(ii) Connect the valve as a triode and note the amplitudes on 1, 2 and 3v input signals. Compare with those obtained in (1) above.

.../Experiment 19

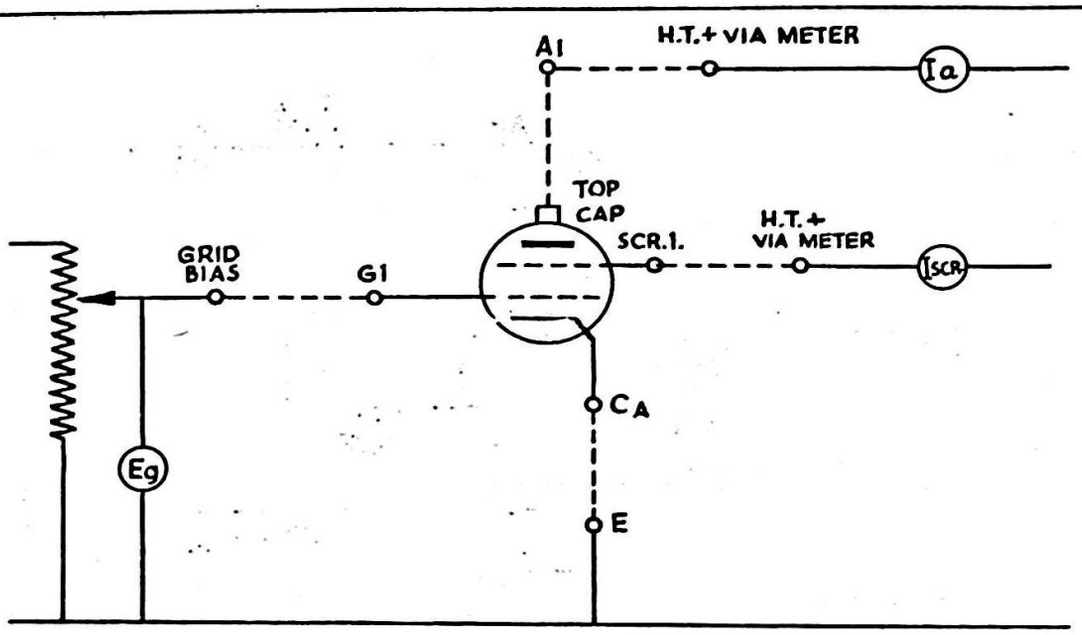

A1
H.T.+ VIA METER
Ia
TOP CAP
SCR.1.
H.T.+ VIA METER
ISCR
GRID BIAS
G1
CA
Eg
E

Fig. 8

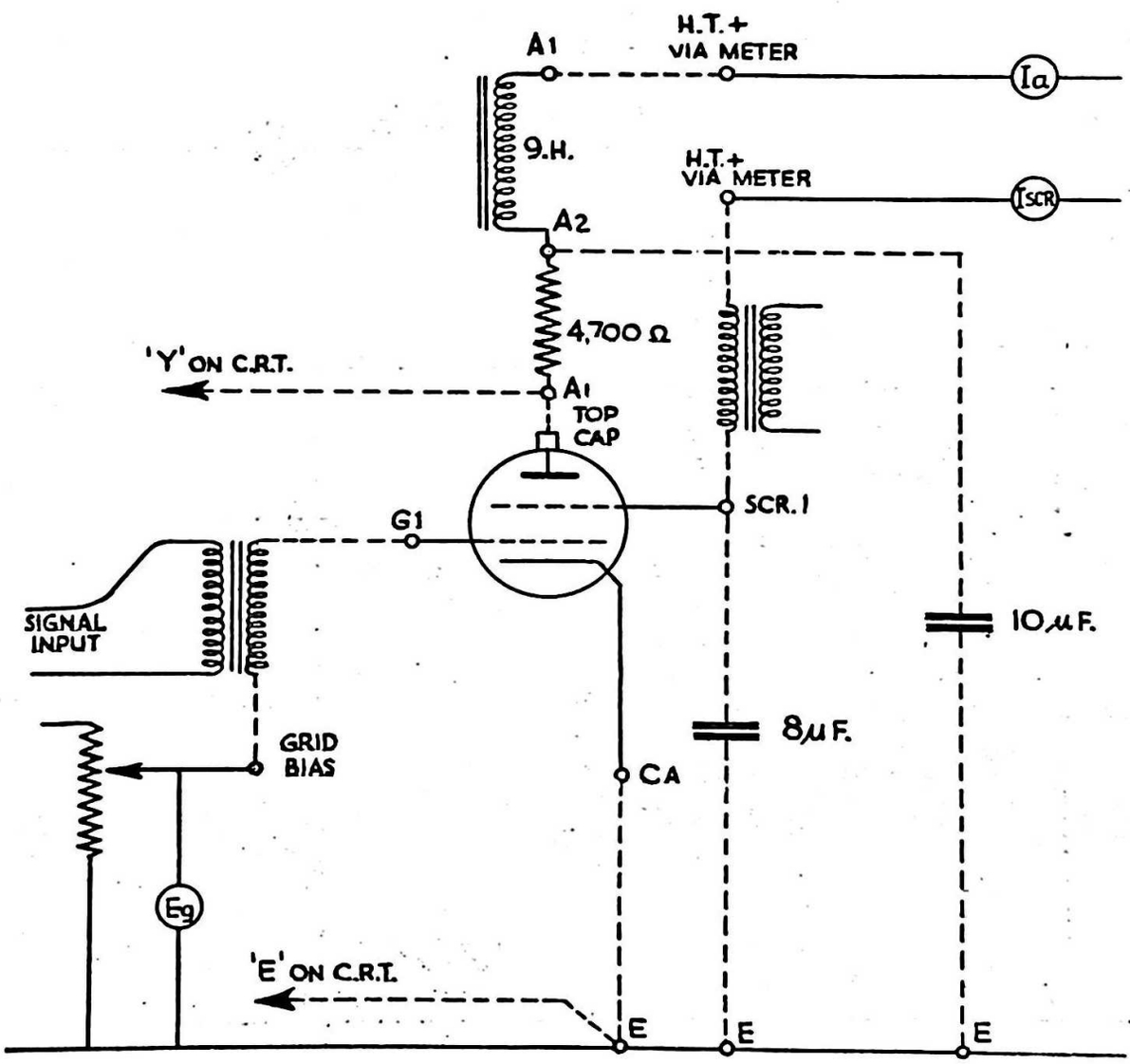

A1
H.T.+ VIA METER
Ia
9.H.
H.T.+ VIA METER
ISCR
A2
4,700 Ω
'Y' ON C.R.T.
A1
TOP CAP
SCR.1
G1
SIGNAL INPUT
10 μF.
8 μF.
GRID BIAS
CA
Eg
'E' ON C.R.T.
E
E
E

Fig. 9

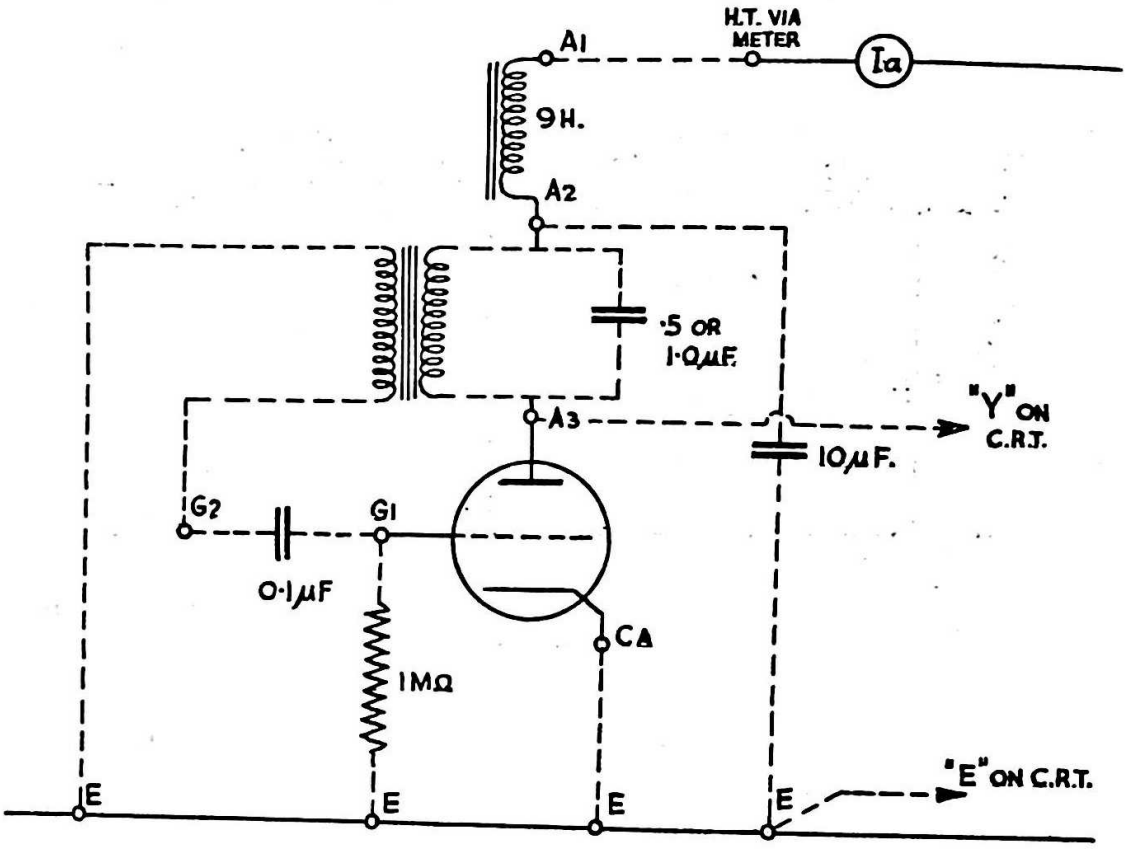

H.T. VIA METER
A1
Ia
9H.
A2
·5 OR 1·0 μF.
A3
"Y" ON C.R.T.
10 μF.
G2
G1
0·1 μF
CA
1 MΩ
E
E
E
E
"E" ON C.R.T.

Fig. 10.

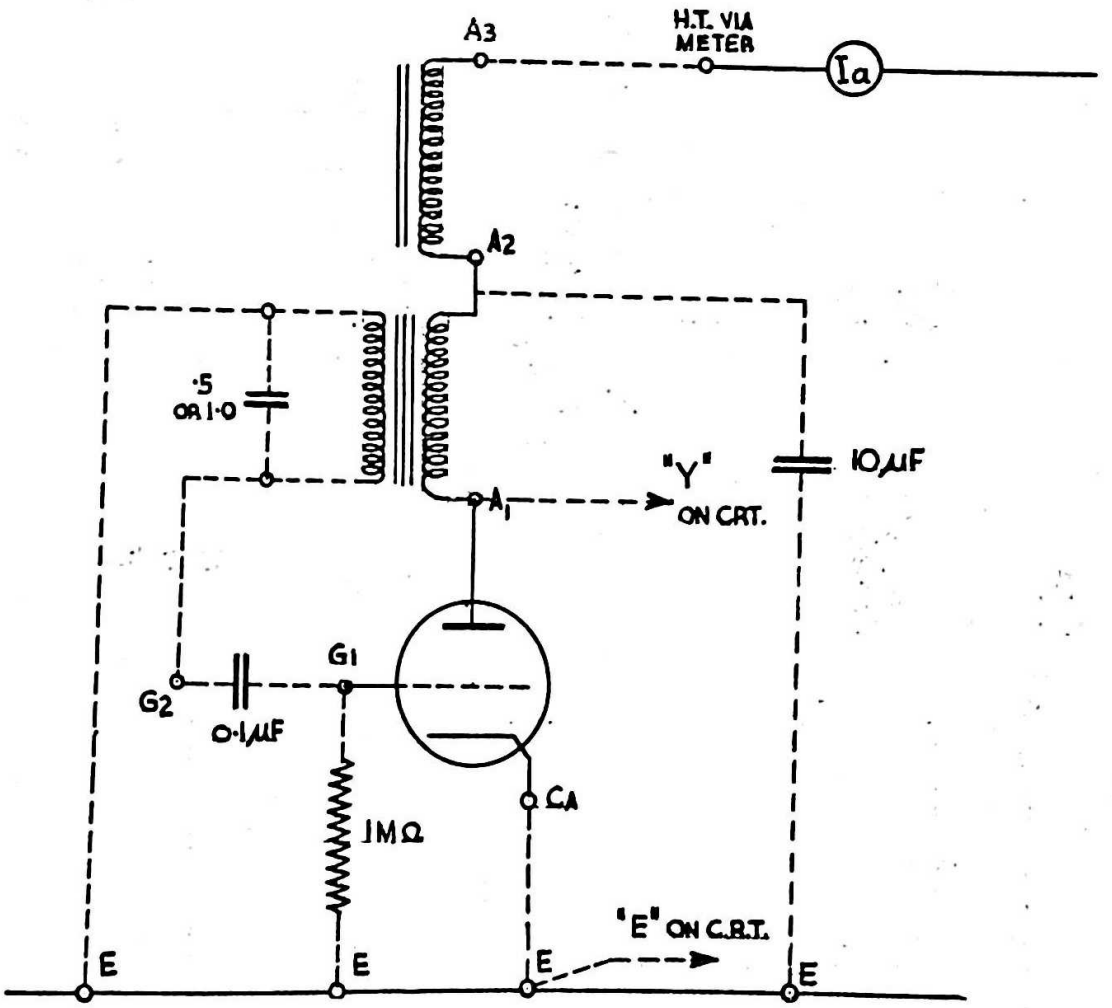

A3
H.T. VIA METER
Ia
A2
·5 OR 1·0
"Y" ON CRT.
10 μF
A1
G1
G2
0·1 μF
CA
1 MΩ
"E" ON C.R.T.
E
E
E
E

Fig. 11

OSCILLATORS - (Experiments 20, 21, 22 and 23)

Experiment 19

Aim and Object : To study the behaviour of a Tuned-Anode. Series - Fed Oscillator.

Apparatus required :
Valve Test Board.
C.R.T.
Transformer
Various small values of condensers
9 Henry Choke
1 Condenser 10 mfd.
1 Resistance 1 megohm
1 Variable Resistance 2,000 ohms.
Valve V.R. 37 Triode.

Diagram of Connections : See Fig.10.

Procedure

Connect up your circuit as in figure 10, using the values of condensers shown. (The circuit should oscillate with these values, but this depends on the properties of the valve).

Before switching on, disconnect the secondary of the transformer from between "G_2" and "E". Connect "G_2" direct to "E". Put about 80v. on the circuit from the supply. Record Ia under these conditions. Now connect the transformer back in circuit between "G_2" and "E". If the value of Ia does not fall by an appreciable amount, then the valve will not be oscillating, and the connections of the transformer on one side must be reversed. (i.e. lead what was on "E" put on "G_2" and lead on "G_2" put on "E").

It must be understood that each valve will have slight variations in its properties so a number of values of Condenser may have to be tried before the valve will oscillate properly. This applies to all the experiments on Oscillators.

When the valve has been made to oscillate correctly, increase Cg until the oscillations are damped. ("Squegger" effect). When damped oscillations have been obtained, connect a variable resistance of 2,000 ohms between "Ca" and "E". This will act as a cathode follower, and oscillations can now be made continuous once again.

Now remove the 2,000 Ohm variable resistance and, having damped oscillations, reduce Gg and note that after a certain value the oscillati ons will cease.

Replace the condenser in the tuned circuit by various values of capacitance and note how the frequency of the oscillations is altered. This can be done by comparing with the Time Base frequency on the C.R.T.

Experiment 20

Aim and Object To study the behaviour of a Tuned-Grid Series - Fed Oscillator.

Apparatus Required As in Experiment 19.

Diagram of Connections See Figure 11.

Procedure

Connect up the circuit as shown in figure 11, and then carry out a similar experimental procedure as that in experiment 19.

.../Experiment 21

Experiment 21

Aim and Object : To study the behaviour of a Tuned-Anode Shunt Fed Oscillator.

Apparatus Required : As in Experiment 19, and in addition:

1 Resistance 33,000 ohms
1 Condenser 8 mfd.

Diagram of Connections : See Figure 12.

Procedure

Connect up the circuit as shown in figure 12, and again carry out the procedure of experiment 19.

Experiment 22

Aim and Object : To study the behaviour of a Tuned-Grid Shunt Fed Oscillator.

Apparatus Required : As for experiment 21.

Diagram of Connections : See figure 13.

Procedure

Connect up the circuit as shown in figure 13, and carry out the same procedure as that in experiment 19.

Experiment 23

LISSAJOU FIGURES

Aim and Object : To produce figures on the C.R.T. (Lissajou Figures) showing the relationship between two frequencies, and thus see how the calibration of an oscillator can be performed.

Apparatus Required : In this experiment two valve test boards are used, each having the components of experiment 19, and in addition a small variable resistance. One C.R.T. will be required between the two boards.

Diagram of Connections : See figure 10, with the following modification. In the condenser branch of the Tuned circuit, place in series with the condenser a variable resistance.

Procedure

Set up the tuned circuit given above, this will be a Tuned Anode Series Fed Oscillator. The connections to the C.R.T. are made so that one oscillator is on the "Y" plate and one on the "X" plates. (i.e. one plate between "Y" and "E", the other between "X" and "E"). The time Base is switched off and a figure is seen on the screen. By varying the resistance in the Tuned circuit or by altering the value of the condenser, the frequencies of each oscillator can be varied and simple figures, such as those in figure 14, can be obtained, showing the relation of the frequencies.

During the course of the period the instructor will bring round to each board a variable oscillator against which the students' oscillators can be examined.

.../Experiment 24

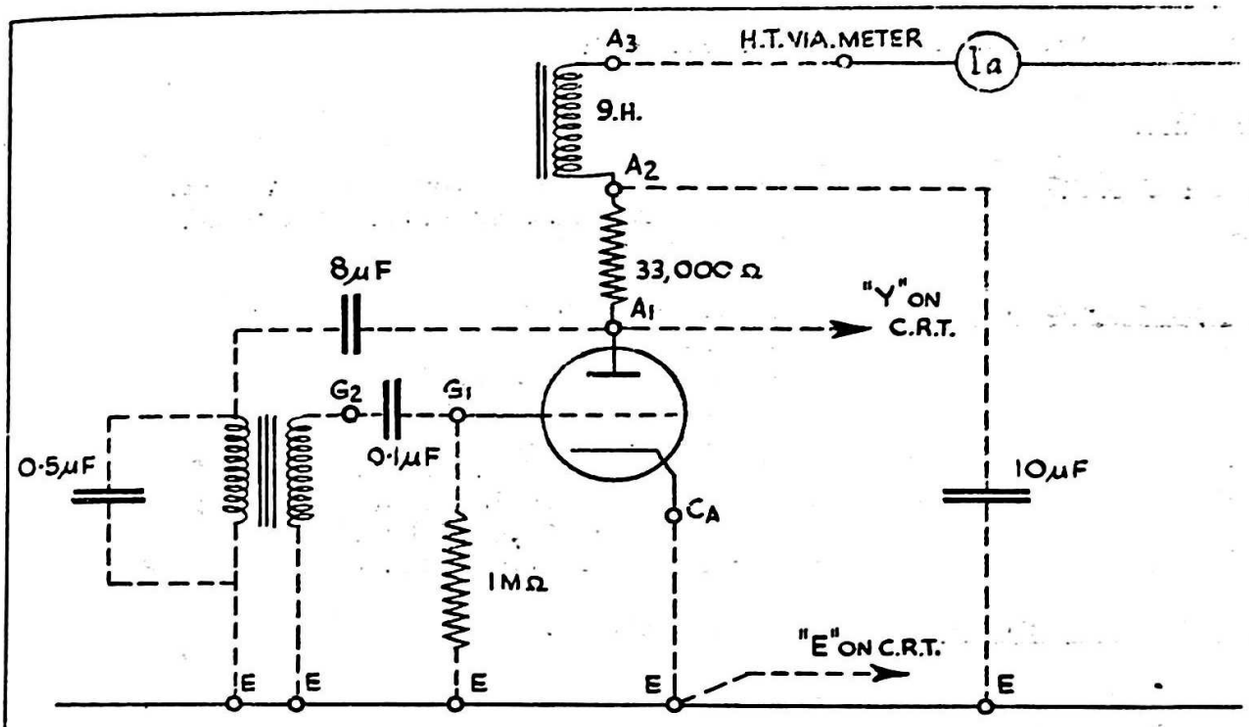


Fig. 12

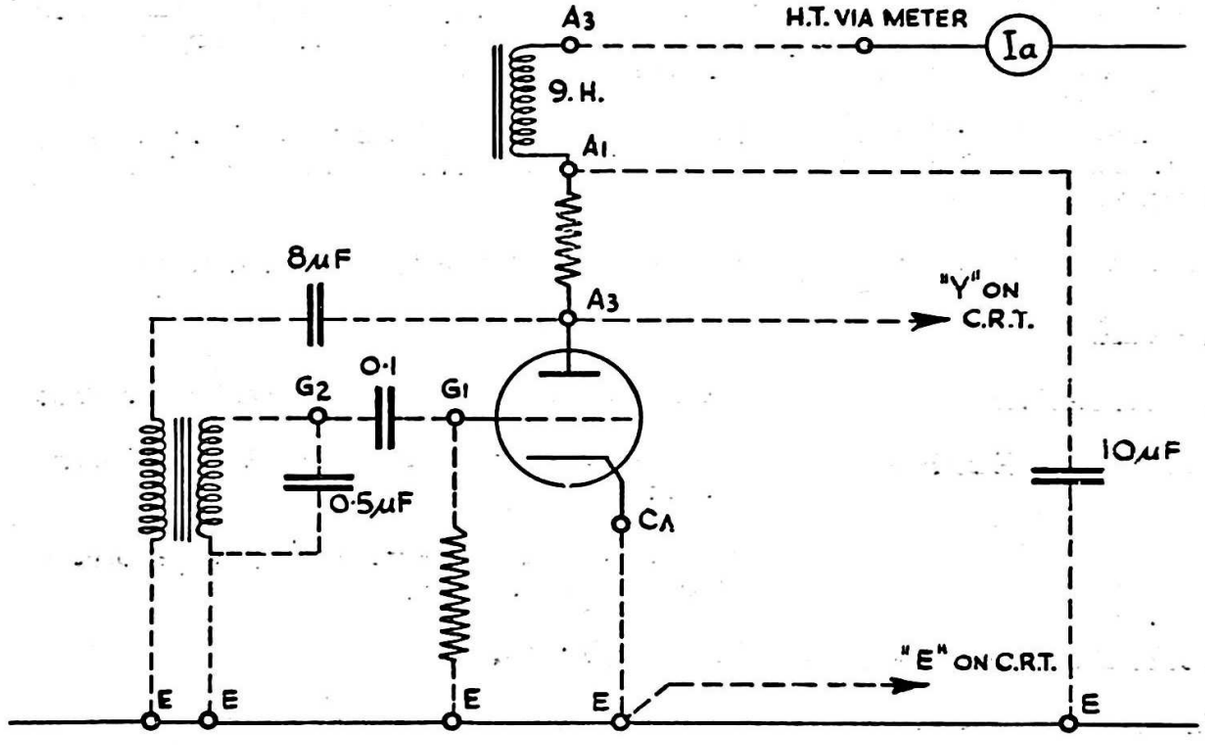


Fig. 13

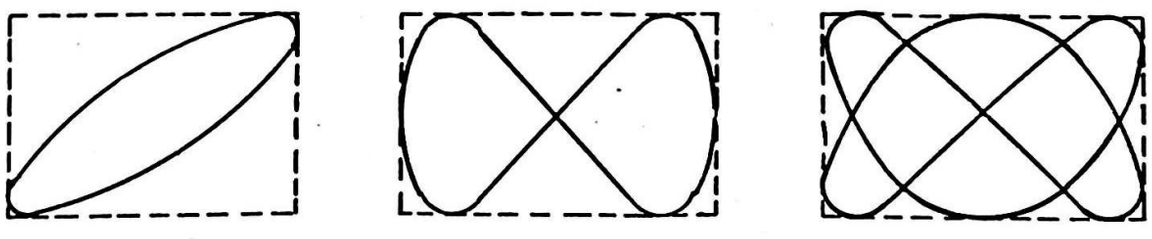


Fig. 14

CATHODE RAY TUBE TIME BASES

Experiment 24

Aim and object : To study the behaviour and wave form of a Resistance capacity Soft valve Time Base.

Apparatus Required :
Valve Test Board.
C.R.T.
1 Choke 9 Henries
1 Condenser 10 mfd
1 Condenser .05 mfds.
1 V.G.T. 126 Thyratron 4V Heater
2 resistance variable 0.25 megohms
1 resistance 20,000 ohms.
1 resistance 1,000 ohms.

Diagram of Connections : See figure 15.

IMPORTANT SWITCH ON THYRATRON HEATER 30 SECONDS BEFORE H.T.

Procedure

Note the shape of wave form on C.R.T. Vary frequency of Time Base against C.R.T. Time Base and note variations in wave form. Vary amplitude and note wave form at maximum amplitude.

Connect terminal marked Cal. on C.R.T. to "Y" plates. This puts 50 c.p.s. sinusoidal on "Y" plates. Put soft valve time base on "B" and "X" plates.

Note resultant wave form and cramping of the wave at one side.

Experiment 25

Aim and Object To study the behaviour of Soft Time Base

Apparatus required As for Experiment 24, with the following additions.

1V.R. 56 valve (pentode) 6.3 V heater.
1 8 mfd. Condenser.

Diagram of Connections : See figure 16.

Procedure

Connect up the circuit as shown in figure 16, and proceed as detailed for experiment 24.

Note the time base is more linear.

.....

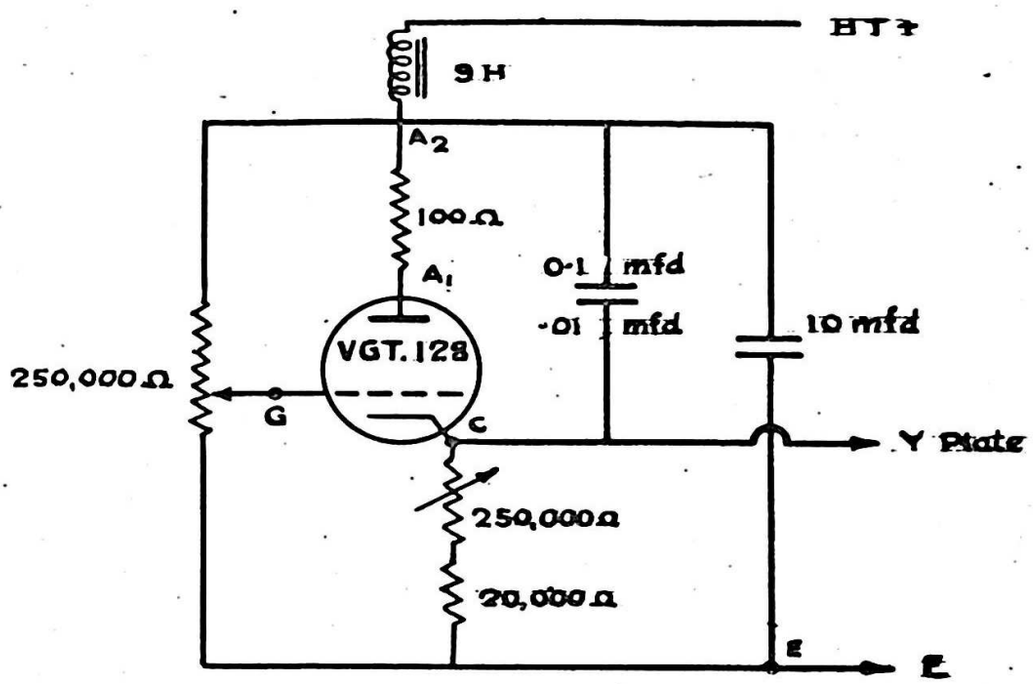

H.T.+
9 H
A2
100 Ω
A1
0·1 mfd
·01 mfd
10 mfd
VGT. 128
250,000 Ω
G
C
Y Plate
250,000 Ω
20,000 Ω
E
E

Fig. 15.

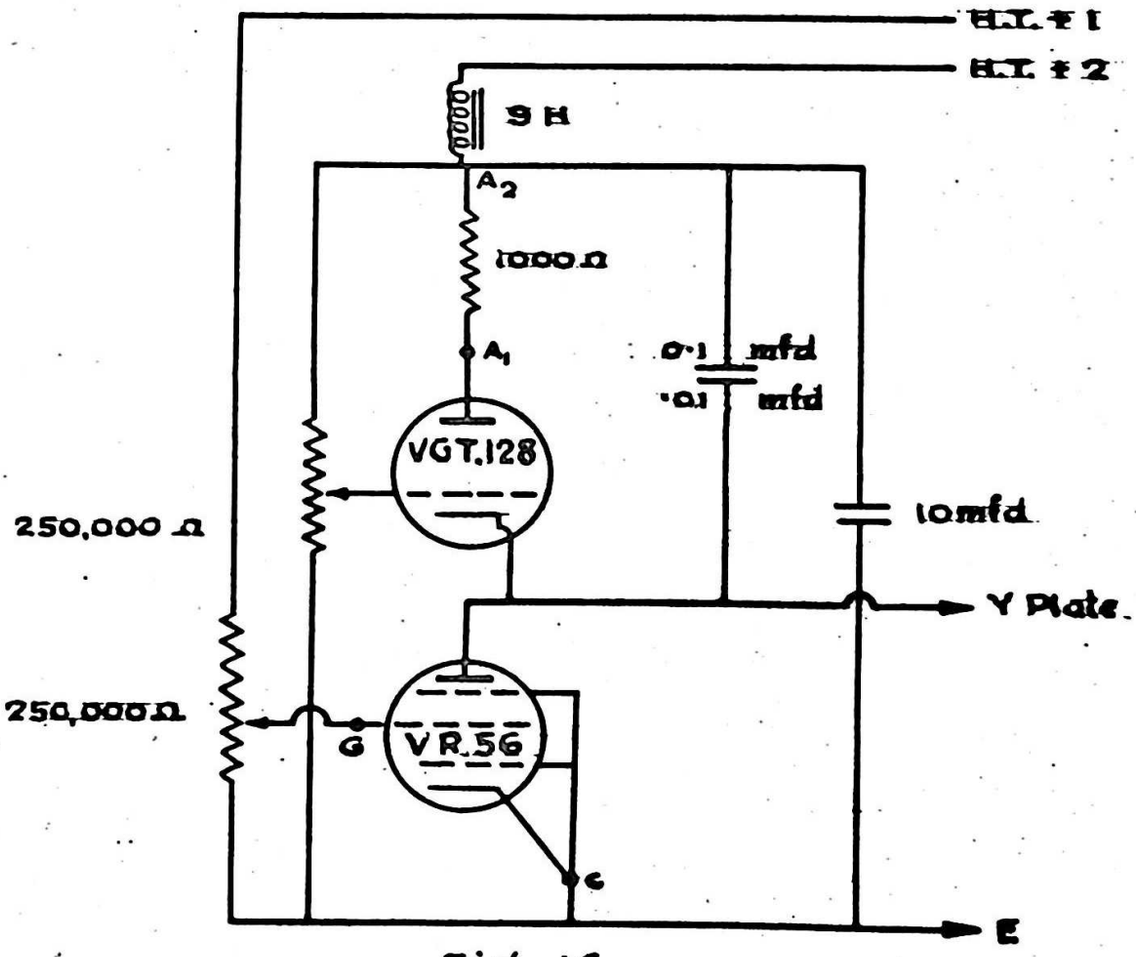

H.T. + 1
H.T. + 2
9 H
A2
1000 Ω
A1
0·1 mfd
·01 mfd
VGT. 128
10 mfd
250,000 Ω
Y Plate
250,000 Ω
G
VR. 56
C
E

Fig. 16.

ELECTRICAL & INSTRUMENT SECTION

HENLOW DIVISION, R.A.F. TECHNICAL COLLEGE

MAGNETISM AND COMPASSES

Instrument Precis No. 3.

Magnetism

1. Natural magnetism is found in certain mineral substances such as lodestone. Magnetism may also be induced in iron or steel by certain physical methods.

The properties of both natural and induced magnets are the same. A substance is magnetic if:-

(i) It attracts pieces or iron and steel which are not magnetised.

(ii) It attracts or repels other magnets.

(iii) When suspended so as to be able to rotate freely in the horizontal plane, it comes to rest in a particular direction. If it is deflected from this position of rest, it oscillates about the position and finally resumes the same attitude. This is a result of (ii) since the earth itself is a large magnet.

2. If a magnetised body is dipped into iron filings, it is found that the filings cling strongly to the ends of the magnet but comparatively feebly to the central portion. It appears that most of the magnetism in the body is concentrated at two points. These points which are not exactly at the ends, but very nearly so, are called the poles of the magnet. If the magnet is freely suspended, the magnetic axis, i.e. the line joining the poles, lies approximately North and South. One pole is called the North-Seeking or Red Pole, and the other the South-Seeking or Blue Pole.

3. When a magnet is brought close to another magnet which is freely suspended, it is found that the two Red Poles or the two Blue Poles repel each other, but that a Red Pole and a Blue Pole attract each other. Hence the important rule:

Like poles repel each other, unlike poles attract each other.

4. A part of space where ther are magnetic forces present is called a magnetic field. This field can be mapped by moving a small compass needle over it and drawing a small line at each point to represent the direction in which the needle points. The aggregate of these constitutes the lines of force which may be defined thus:

A line of force is a curve drawn in the magnetic field so that the tangent to it at any point gives the direction of the magnetic force at that point.

The Molecular Theory of Magnetisation

5. Magnetic material which has not been magnetised is made up of a very large number of very small magnets whose axes are scattered at random in all possible directions.

.../The many

The many fields of the molecular magnets neutralise each other, and so the bar as a whole does not behave as a magnet. If, however, the axes of the small magnets are all made to point in the same direction, then their magnetic fields reinforce each other.

The bar will now possess magnetic properties, it has become magnetised. The degree of magnetisation depends upon the degree of alignment of the small magnets. The limit is reached when all the magnets are in line. The material is then said to be magnetically saturated.

If a magnet is broken up into a number of small pieces, it is found that each of these pieces is itself a magnet with a red pole and a blue pole, but it is impossible to obtain an isolated red or blue pole no matter how far the breaking-up is continued.

The Magnetic Characteristics of Hard and Soft Iron

6. The ease with which the molecular magnets can be aligned classifies magnetic material into "hard" and "soft" varieties. Metals of the "hard" type are difficult to magnetise, but, once magnetized, retain that property for a considerable length of time. On the other hand, metals of the "soft" type are easily magnetized, but generally lose that property once the magnetizing force has been removed. Wrought iron is generally of the "soft" type, while cobalt and tungsten steels are of the "hard" type.

Some Methods of Magnetisation

7. (i) By Induction

If a piece of magnetically-neutral iron or steel is placed in a magnetic field, the molecular magnets will tend to leave their haphazard arrangement and align themselves along the lines of force with their Red Poles towards the Blue Pole of the magnetising field. In this way, the metal become magnetised. Therefore when magnetically neutral material is placed near a magnet it becomes a second magnet which will react upon the first. (In the case of hard metals, hammering may be necessary to assist the alignment process).

(ii) By Stroking

The piece of metal to be magnetised is laid flat and stroked in one direction only with one pole of a powerful magnet. If a red pole is used, the blue poles of the metal's elementary magnets will try to follow the red stroking pole, and thus rearrange themselves into the required lines. If a greater effect is desired, the blue pole of one magnet and the red pole of another should be used, stroking outwards from the centre in opposite directions.

(iii) By Solenoid

When an electric current passes through a coil of wire, the coil of wire becomes a magnet (see para. 11). Such coils of wire are called Solenoids.

If a piece of metal to be magnetised is placed within such a coil, and the current switched on, magnetisation of the metal will take place by induction (See Fig. 1). This method is generally used when a powerful magnetising force is required, as in the case of the "hard" cobalt steel magnets of an aircraft compass.

.../Magnetic

Magnetic Saturation

8. The magnetisation of a piece of metal can be continued to any desired degree of intensity until a point is reached beyond which further application of the magnetising force produces no increase in the magnetic strength of the metal. When this point is reached, the metal is said to be magnetically "saturated".

De-Magnetisation

9. A magnetized piece of metal can be de-magnetized by jumbling up the elementary magnets in the metal, or disturbing the orderly arrangement necessary for the formation of an external magnetic field. In the case of "soft" iron this can be done by merely removing the magnetising force. "Hard" iron presents a rather more difficult problem.

10. A very thorough method of de-magnetising "hard" iron is used when treating aircraft components such as undercarriages, moveable flap gear and so forth. A single-phase alternating current (in the order of 250 volts, 50 cycles) is sent through the winding of a large solenoid, and the component to be de-magnetized is then passed from one end to the other through the middle of the coil.

The current is then reduced, and the component again passed through the coil in the same direction. The alternating magnetic field of the coil, when applied in this manner, is sufficient to jumble up the elementary magnets in the metal and de-magnetise it completely.

Other methods of de-magnetisation include heating the metal to a certain temperature and hammering it in a field of opposite polarity. Either of these methods will jumble up the elementary magnets of the metal, though the heating method is probably the most thorough.

Magnetic Properties of an Electric Current

11. If an electric current is flowing along a straight piece of wire it produces a magnetic field around the wire as shown in Fig.2. The field is built up of innumerable circular lines of force concentric with the wire.

If such a length of wire is wound into a coil, as in Fig.3, it becomes a solenoid. The fields of adjacent windings combine and a magnetic field is formed along the axis of the solenoid. The field strength is proportional to the current flowing and to the number of turns in the coil. As stated before, a piece of magnetisable material placed inside the coil becomes magnetised by induction.

THe Inverse Square Law

12. The force existing between two poles varies inversely as the square of the distance between them. Generally speaking it is impossible to isolate single poles, and the more practical law covering cases where both poles of a magnet are effective is that the force varies inversely as the CUBE of the distance. A practical expression of this law is as follows:-

$$\frac{\text{New deviation}}{\text{Old deviation}} = \frac{\text{Old distance}^3}{\text{New Distance}^3}$$

The above formula is used for determining the amount of deviation which will be caused when a piece of magnetic material is placed at different distances from, say, the needle of an aircraft compass.

Example

13. A metal instrument placed 12 inches from an aircraft compass causes a deviation of 5^o with the aircraft on a certain heading. To what distance must the instrument be moved so as to reduce the deviation to 1^o?

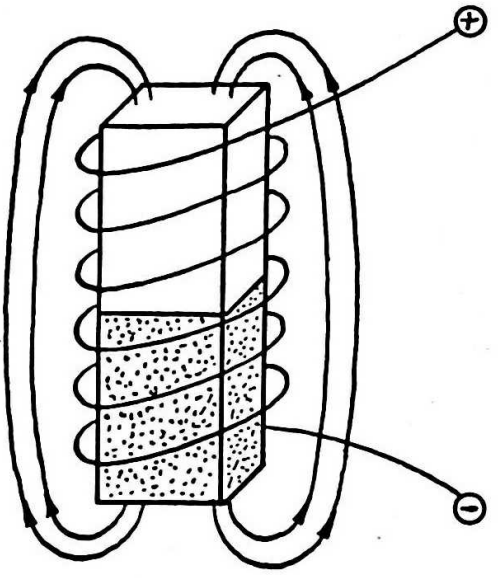


Fig 1.

MAGNETISATION BY SOLENOID.

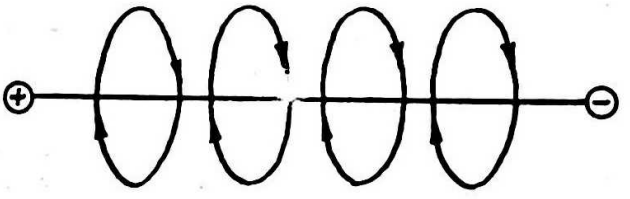


Fig. 8 a.

MAGNETIC FIELD PRODUCED BY
ELECTRIC CURRENT IN A WIRE.

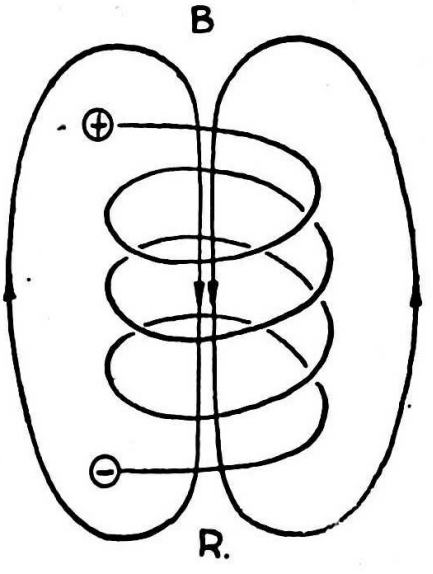


Fig. 8 b.

MAGNETIC FIELD PRODUCED BY
ELECTRIC CURRENT IN A SOLENOID.

From the above:-

Old deviation	=	5°
New deviation	=	1°
Old distance	=	12 inches

The calculation then becomes:-

$$\frac{1^\circ}{5^\circ} = \frac{12^3}{\text{New distance}^3}$$

$$\therefore \text{ New Distance} = \sqrt[3]{5 \times 12^3} \text{ inches.}$$

$$= 20.5 \text{ inches.}$$

The Moment of a Magnet

14. The moment of a magnet is the most important characteristic of the magnet and corresponds, say, to the horse power of an engine. It is, briefly the power of the magnet. Before it can be properly defined, two other elementary definitions are necessary:

(i) Unit Pole:

When two exactly similar poles, placed 1 cm. apart, exert on each other a force equal to 1 dyne, * each is said to be a unit pole.

(ii) Unit Field:

When a unit pole, placed in a magnetic field, is acted upon by a force equal to 1 dyne, unit field is said to exist at that point.

15. The moment of a magnet may be defined as follows:-

"The moment of a magnet is equal to the moment of the couple necessary to maintain it at right angles to a magnetic field of unit intensity".

From this it can be seen that the greater the pole strength and the greater the length of a magnet the greater will be its tendency to turn into line with a surrounding magnetic field. Conversely, the greater will be the power it exerts upon the surrounding field or indeed upon any magnetic material in its vicinity.

It is therefore evident that the moment of a magnet (usually expressed in c.g.s. units) is an indication of the strength of the magnetic influence it can exert.

Magnetic Shielding

16. A space which is shielded by a shell of "soft" magnetic metal contains only a small percentage of the lines of force of an external magnetic field which would otherwise be present. Most of the lines of force are directed to and pass along the body of the "soft"shield. Therefore the directive force of the earth's magnetic field will be greatly reduced in an aircraft where there is much protective armour plate.

* A dyne is the force required to produce an acceleration of 1cm. per second, per second in a mass of 1 gramme.

TERRESTRIAL MAGNETISM

General

17. The surface of the Earth is covered by a weak magnetic field which culminates in two internal Magnetic Poles, situated near the North and South Geographic Poles. The North Magnetic Pole is "blue" in character, and the South Magnetic Pole is "red".

The Earth's magnetic field differs from that of an ordinary magnet in several respects. Its points of maximum intensity or strength are not at the Magnetic Poles, but occur at four other positions, two near each pole, known as magnetic foci. The Magnetic poles themselves are continually changing their positions. Moreover, the field is not symmetrical and is continually varying its direction relative to the True meridians.

The Principle of the Magnetic Compass

18. A freely-suspended magnetic needle will align itself with the Earth's field, N. end to the North, if undisturbed by other magnetic influences. (See paragraph 22). The line on the Earth's surface which is parallel to the needle is known as the Magnetic Meridian at the point in question.

Since at any point the angle (known as Variation) between the Magnetic Meridian and the True Meridian can be measured, and its changes accurately predicted, the freely-suspended magnetic needle can be used as a datum from which to measure direction on the Earth's surface.

The Earth's lines of magnetic force are vertical to the surface at the Magnetic Poles and parallel to the surface midway between them. A freely-suspended magnetic needle, on a journey from one Magnetic Pole to the other, would therefore commence by being vertical to the Earth's surface and then pass through decreasing angles of depression until it became horizontal. Its angle of depression would then gradually increase until the needle was vertical once more. The angle such a needle makes with the horizontal at any given point on the Earth's surface is known as Magnetic Dip.

The magnet system of a compass is so balanced on its pivot that it always remains practically horizontal and is affected only by the horizontal component of the Earth's magnetic force. It is thus more suitable for indicating direction than a freely-suspended needle lying inclined at the local angle of Dip. Whenever, therefore, the Earth's magnetic field has an appreciable horizontal component, a magnetic compass will function satisfactorily.

Terrestrial Limitations of the Magnetic Compass

19. The unsymmetrical line round the Earth along which Magnetic Dip is zero (i.e. where the lines of force of the Earth's magnetic field are horizontal) is known as the Magnetic Equator. It coincides very roughly with the Geographic Equator. At all other points on the Earth's surface the line of total terrestrial magnetic force has a Dip depending on the proximity of each point to the Magnetic Poles.

Wherever Dip exists, the line of total terrestrial magnetic force can be analysed into two components, one horizontal and the other vertical, known as H and Z respectively. (See Figure 4).

The strength of the horizontal component varies with the cosine of the Dip, being at a maximum along the Magnetic Equator (Dip nil,) decreasing towards the Magnetic Poles and disappearing altogether directly over them (Dip 90°). Since a magnetic compass depends solely upon the horizontal component for its directional properties, it will obviously cease to operate over the Magnetic Poles and will be extremely sluggish

.../in their

in their immediate vicinity.

Generally speaking, the magnetic compass of an aircraft becomes unreliable where the Dip exceeds 75°. It will operate at its best in the vicinity of the Magnetic Equator.

Variation

Variation has been referred to in the preceeding paragraphs as the angle between the True and Magnetic meridians at any point. It is named Westerly when the red end of the compass needle lies to the West of the True Meridian, and Easterly when the red end of the compass needle lies to the East of the True meridian. (See fig.5).

Its accurate measurements and prediction is of great importance since it forms an essential step between the indications of the magnetic compass and the calculations of the Navigator. Numerous observatories have been set up all over the World, to measure Variation and predict its slow changes. Special magnetic survey ships, built mainly of wood, are used for carrying out the work at sea.

Variation is plotted on maps and charts in the form of Isogonals, which are lines joining points or equal Variation. It is also recorded on the compass roses of maps with a statement of its annual change of magnitude.

Dip and Horizontal Force

21. Other work carried out by the observatories and survey ships includes the plotting of Horizontal Force and Dip. The latter is plotted on special charts in the form of Isoclinals, which are lines joining points of equal Dip. Isoclinals conform very roughly to the Geographic Parallels of Latitude. Because of this, the term Magnetic Latitude is sometimes used instead of Dip.

The Magnetic Compass

22. The magnetic compass has survived through the ages as an indispensable and universal aid to Navigation because nothing better has yet been devised to take its place. It is a simple instrument to construct, easy to maintain and robust in operation; but, before it can serve its purpose which is to provide an accurate indication of True North, certain limitations must be taken into account.

The compass needle (a term which includes all types of compass magnet systems) if affected only by the Earth's Magnetic Field, will lie along the local magnetic meridian with its red end indicating local Magnetic North. Under these circumstances, the only correction to be applied to obtain True North is the local Variation, the Navigator merely applying this as requisite.

Unfortunately, however, aircraft compasses are seldom so ideally situated. Modern aircraft are full of metal components, some permanently magnetised during construction, some temporarily magnetized during flight, and other in which the magnetism changes with movement of the aircraft. So the compass needle, even though positioned as far as possible from such components, is nearly always affected by them and deflected from the Magnetic meridian.

.../This angle

This angle of deflection is known as the Deviation of the compass, and is named + (or East) when the red end of the needle lies to the East of the Magnetic meridian, and - (or West) when the red end of the needle lies to the West of the Magnetic meridian.

Where Deviation exists, the red end of the compass needle will indicate what is known as Compass North.

The Application of Deviation and Variation

23. The terms "Compass", "Magnetic" or "True" are used to prefix all directions (bearings, Courses and tracks) to indicate whether they have been measured from Compass, Magnetic or True North respectively.

All Compass direction may be converted to their equivalent Magnetic directions by applying the Deviation to which the compass needle is subject at that time. The sign + or - in front of the Deviation indicates how it must be applied to Compass directions to obtain Magnetic directions. In other words, Deviation is a correction to a compass reading.

The Magnetic directions may be converted to True directions by applying the local Variation to the former, adding if Easterly, subtracting if Westerly.

Conversion of True directions to Magnetic directions, and Magnetic directions to Compass directions can be done with equal ease, remembering that Variation and Deviation must be applied in the opposite way to that stated above.

Examples

24. (i) The Compass bearing of a distant object is 219°. Local Variation is 11°W. Deviation of the compass is +4°(E).

What is (a) the Magnetic bearing, and (b) the True bearing?

Compass bearing	=	219°
Deviation (E)	=	+ 4° ... "Compass least"
(a) Magnetic bearing	=	223°
Variation (W)	=	11° ... "Magnetic Best"
(b) True bearing	=	212°

(ii) The True Course of an aircraft is 138°
Local Variation is 12°E. Deviation of the compass is -4°(W).
What is (a) the Magnetic Course, and (b) the Compass Course?

True Course	=	138°
Variation (E)	=	- 12° ... "Magnetic least"
(a) Magnetic Course	=	126°
Deviation (W)	=	+ 4° ... "Compass Best"
(b) Compass Course	=	130°

.../The Elimination

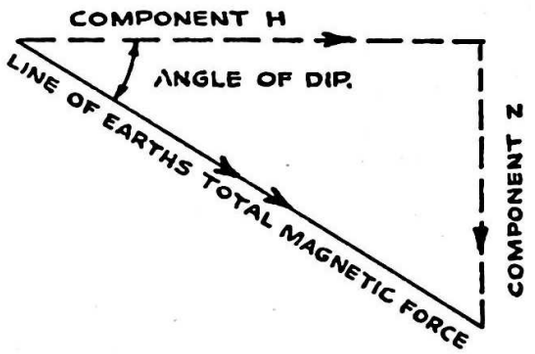


Fig. 4.

THE COMPONENTS COMPRISING THE EARTHS MAGNETIC FORCE

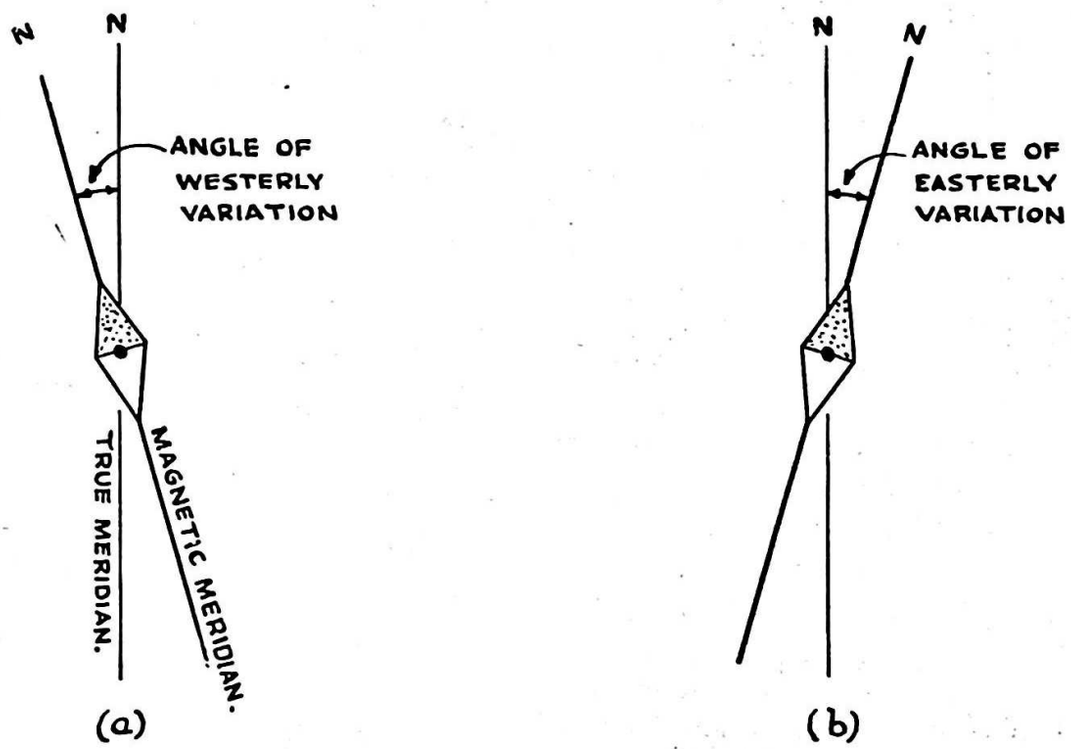


Fig. 5.

VARIATION.

The Elimination of Deviation

25. Deviation, as has been explained, is an error of the compass indication brought about by local magnetic effects in the aircraft. It can be minimized by neutralising the resident components of aircraft magnetism. Beyond this, nothing further can be done and Deviation due to transient causes must be determined by the Navigator when possible and allowed for in his calculations.

If it is required to neutralise the effect of a certain magnet, the easiest way is to place another magnet of equal strength but opposite polarity adjacent to it; the red pole of one will exactly oppose the effect of the blue pole of the other. This is the principle employed in aircraft to nautralize unwanted permanent magnetism and certain "soft" iron defects inseparable from it.

Analysis of Aircraft Magnetism

26. The permanent magnetism is mostly induced during construction by the Earth's field. The fuselage during assembly receives a large amount of hammering, especially if much riveting takes place, and since it remains stationary in the workshop for the majority of the time, the continual hammering will help the molecules of the metal in their tendency to align themselves with the Earth's magnetic field. They will, in fact, be slowly jolted into alignment. Thus, any metal of the "hard" variety in the fuselage will become permanently magnetized with a polarity depending on the heading of the fuselage during assembly. That half of the fuselage nearest to local Magnetic North will contain the red pole, and that nearest to local Magnetic South the blue pole.

Since the Earth's magnetic field in this country has an angle of Dip of about 67°, fuselages built here will be magnetized permanently in the vertical plane as well as the horizontal.

In the case of a fuselage built heading NE in this country, the permanent magnetization will appear as in Figure 6(a) and (b).

27. During normal flight the aircraft and the compass needle are both horizontal. Therefore, except in special circumstances, it is necessary to consider only that part of the permanent magnetism in the aircraft which is horizontal in effect. (See figure 6(a)).

If an attempt were made to neutralise the effect as it is, by placing a magnet with opposite polarity diagonally across the aircraft, considerable difficulty would be experienced in determining at just what angle the magnet was to be placed and what strength of magnet was to be employed.

So, to simplify correction, the aircraft's diagonal magnetism is analysed into two component parts, one fore-and-aft and the other athwartships. The precise effect of each of these components can easily be measured in the form of compass Deviation; neutralising magnets (usually called corrector magnets) of the required strength can then be placed fore-and-aft and athwartships as required. For convenience, the horizontal fore-and-aft component of the aircraft's permanent magnetism is known as P, and the horizontal athwartships component Q. (See Figure 7). The vertical component only considered in certain cases, is known as R.

Vertical "soft" iron in aircraft, magnetized by the Earth's field, can have the same effects upon the compass as components P and Q, and will act with the latter in their respective fore-and-aft and athwartships planes.

28. Component P and its allied "soft" iron can be represented by a single magnet of similar strength and polarity lying fore-and-aft. In the aircraft referred to above, this magnet would lie with its red end forward and blue end aft. Its effect upon the magnetic compass needle can best be understood with reference to Figure 8(a).

.../The maximum

The maximum Deviation will be caused when the fore-and-aft magnet is at right-angles to the compass needle. This occurs when the aircraft is heading East or West by compass, the sign of Deviation on East being opposite to that on West. In the case under consideration, the signs will be - and + respectively. Zero Deviation will occur when the aircraft is heading North or South by compass, in which positions the fore-and-aft magnet is in line with the compass needle. Intermediate amounts of Deviation occur at other headings.

An appropriate curve showing changes of Deviation due to P with changes of compass heading is given in figure 8 (b). If drawn accurately it would be a sine curve.

29. Similar treatment of Q and its allied "soft" iron in the aircraft under consideration gives the diagram and cosine curve in Figure 9 (a) and (b).

Maximum Deviation due to this cause occurs on the North and South compass headings, the sign of Deviation on North being opposite to that on South. In the case under consideration, the signs will be + and - respectively.

Coefficients B and C

30. Coefficients B and C are the calculated quantities of Deviation due to P and Q respectively. (Vertical "soft" iron effects are included).

Coefficient B is the algebraic value of the Deviation produced by component P and its allied vertical "soft" iron when the aircraft is heading Magnetic East. It is calculated by the following formula:

$$B = \frac{(\text{Deviation on Magnetic East} - \text{Deviation on Magnetic West})}{2}$$

Example

31. When swinging an aircraft, the following Deviations were determined:

Deviation on Magnetic East = $+3^\circ$

Deviation on Magnetic West = -5°

$\therefore$ Coefficient B $= \frac{+3^\circ - (-5^\circ)}{2} = \frac{+3^\circ + 5^\circ}{2} = +4^\circ$

Coefficient C is the algebraic value of the Deviation produced by component Q and its allied vertical "soft" iron, when the aircraft is heading Magnetic North. It is calculated by the following formula:

$$C = \frac{(\text{Deviation on Magnetic North} - \text{Deviation on Magnetic South})}{2}$$

Example

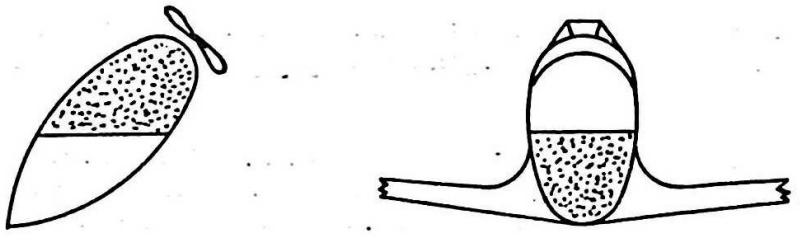
32. The following Deviations were found when swinging an aircraft:

Deviation on Magnetic North = -2°

Deviation on Magnetic South = $+4^\circ$

$\therefore$ Coefficient C $= \frac{-2^\circ - (+4^\circ)}{2} = \frac{-2^\circ - 4^\circ}{2} = -3^\circ$

.../Coefficient A

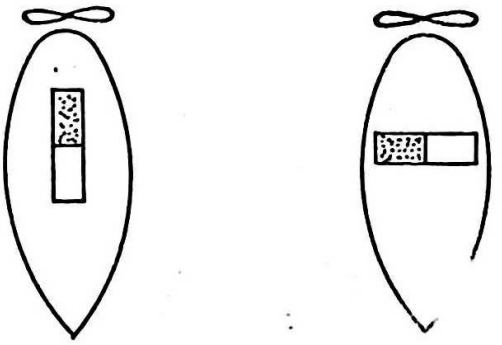


PLAN VIEW (a.)

SECTION AMIDSHIPS (b)

Fig. 6.

MAGNETIZED FUSELAGE



COMPONENT P

COMPONENT Q

Fig. 7.

HORIZONTAL COMPONENTS P. & Q.

Coefficient A

33. An aircraft compass, when installed correctly, has its lubber line (the mark which represents the aircraft's head and against which Courses are read) exactly in the fore-and-aft line passing through the compass position. If, however, the lubber line is displaced, all Courses read against it will have an error equal to the number of degrees by which it is out of alignment. For example, if the lubber line be displaced 3° to Starboard of the fore-and-aft line, all Courses read will be 3° too great. If a Course of 048° is indicated, the correct heading would be 045° and so on. The compass would, under these circumstances, have an apparent Deviation, constant on all headings, of -3°.

Certain arrangements of horizontal "soft" iron can also produce a constant Deviation indistinguishable from the mechanical kind referred to above. It is seldom of any appreciable value.

Constant Deviation, two causes of which are given above, is known as coefficient A.

To eliminate coefficient A it is necessary merely to rotate the whole compass until the lubber line is correctly positioned. It is calculated by the following formula:

$$A = \frac{(\text{Deviations on Magnetic N} + \text{NE} + \text{E} + \text{SE} + \text{S} + \text{SW} + \text{W} + \text{NW})}{8}$$

Example

34. The following Deviations were found when swinging an aircraft:

Magnetic Heading	Compass Deviation
N	-1°
NE	-3°
E	-5°
SE	-2°
S	0°
SW	+1°
W	+2°
NW	0°

$$\text{Coefficient A} = \frac{-1^\circ \ -3^\circ \ -5^\circ \ -2^\circ \ +1^\circ \ +2^\circ}{8} = \frac{-8^\circ}{8} = -1^\circ$$

Coefficients D and E

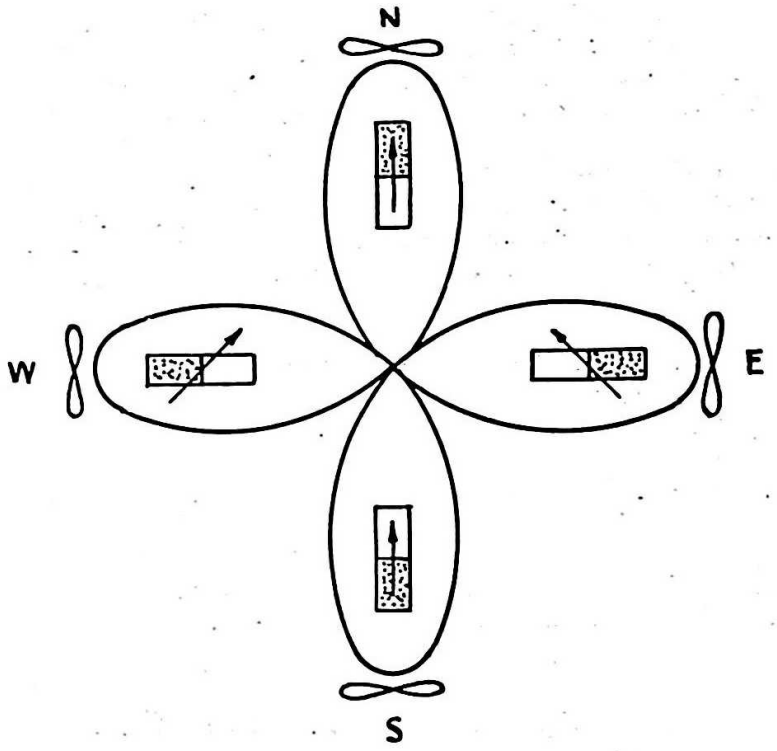
35. These coefficients are caused by horizontal "soft" iron magnetism.

D is sometimes appreciable in aircraft, being the value on Magnetic North-East of the Deviation due to symmetrical horizontal "soft" iron. This Deviation is maximum on NE, SE, SW AND NW, being zero on the cardinal headings and changing its sign every 90°. Correction for Coefficient D, although not often made, can be effected by the introduction of soft iron spherical correctors placed about the compass position. Correction for Coefficient E may be made in the same manner.

Swinging an Aircraft for Compass Adjustment.

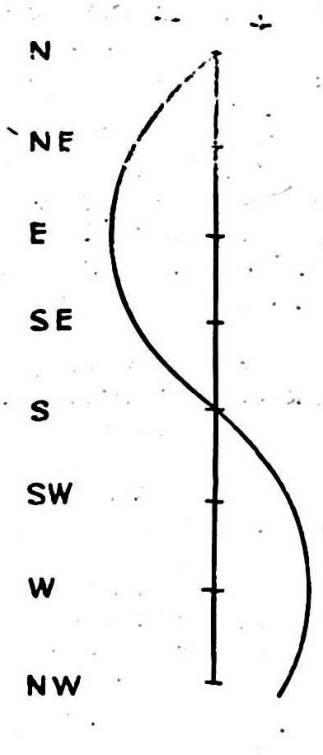
36. The purpose of swinging an aircraft is two-fold. First, it is to neutralise as much of the aircraft's magnetism as possible and thereby to provide the compass with a position in which it can operate to the best advantage. Second, it is to tabulate for the information of the Navigator any Deviations remaining after the coefficients A, B and C have been eliminated.

.../For accurate



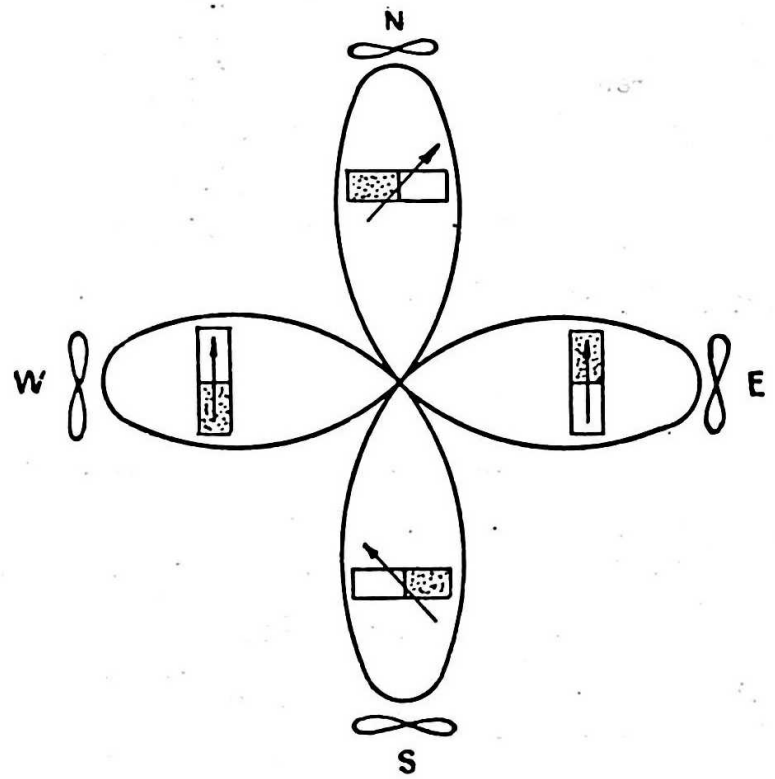
(a)

Fig. 8.



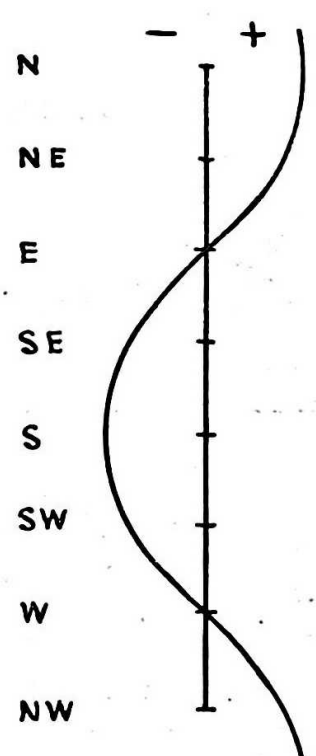
(b)

TYPICAL EFFECT OF P AND ITS ALLIED SOFT IRON.



(a)

Fig. 9.



(b)

TYPICAL EFFECT OF Q AND ITS ALLIED SOFT IRON.

For accurate and reliable results, aircraft should be swung under the conditions in which the compass is normally used, namely, in cruising flight. When this is not possible, aircraft must be swung on the ground.

Swinging, combined with the simple servicing schedule described in paragraph 83, should be carried out at the times specified in K.R. and A.C.I., para. 762. This will ensure the best possible service from compasses at all times.

37. The elimination of coefficients B and C is brought about by the introduction of magnetic fields at the compass position of such strength and polarity that they exactly neutralize components P and Q and their allied components (due to vertical "soft" iron). These neutralizing magnetic fields are produced by either of two devices.

(i) The first of these devices is obsolescent and consists of a block of wood secured beneath the compass. In this block are a number of holes, some drilled fore-andaft and other athwartships. Small magnets are inserted in the fore-and-aft holes until coefficient B is eliminated, and in the athwartships holes until C is eliminated.

(ii) The second device, in general use throughout the Royal Air Force and sometimes known as the micro-adjuster, consists of a circular metal bos secured beneath the compass. Inside the metal box are two pairs of magnets, one pair lying fore-and-aft and the other athwartships. When neutral, the magnets in each pair lie parallel, with opposite poles adjacent. If a magnetic field is required to neutralize P or Q, the appropriate pair of magnets is opened scissorwise by gearing, until it forms a cross. This is achieved by means of a special key inserted and turned in either of two external control heads. The opening of the magnets causes a magnetic field to be released for neutralizing purposes. The further the magnets are opened, the stronger the field becomes.

There are four external control heads, two diametrically opposite for each pair of magnets. It should be remembered that the key must always be used in either of the two control heads whose common axis lies at right-angles to that of the compass needle at the time.

38. To compute the necessary Deviations, the magnetic headings of the aircraft, obtained from external sources, are compared with the respective compass headings. The magnetic headings may be obtained in either of two ways:

(i) If using a compass base, the aircraft can be aligned on the compass base lines as requisite. It is as well to ensure that the base has been calibrated within the last 4 years. The last date of calibration should be found painted on it.

(ii) If a compass base cannot be used, the best method is to place a landing compass, or a convenient type of bearing compass, accurately ahead or astern of the aircraft and not less than 30 yards from it. A bearing along the centre line of the aircraft will then give the magnetic heading. Care must be taken to keep the compass used well away from any local disturbing magnetic influence.

.../When reading

39. When reading the compass in the aircraft, care must be taken to keep the eye vertically above the centre of the compass in question. Considerable reading errors due to parallax will occur if this is not done owing to the fact that the aircraft is usually 10° - 15° tail down, and the compass graduations accordingly inclined to the compass needle.

If accurate results are to be obtained, compass adjustment must never be rushed. Compasses must be given plenty of time to settle down on each heading. Slight tapping of the compass will be found to assist this. Corrections, if carried out, must be done carefully and with patience; slight tapping of the compass will again aid the process.

The use of engines during swinging on the ground is optional. Since they cannot be run continuously at cruising r.p.m. to simulate actual flying conditions, there is no object in using them except for manoeuvring.

Procedure for Swinging

40. The process of swinging is divided into three distinct phases. The first of these is the correcting swing, during which coefficients B and C are computed and eliminated with whatever corrector device is fitted. The second is the check swing, the object of which is to determine what Deviations remain. The third is the computation and removal of coefficient A and the recording of residual Deviations for the information of the Navigator.

41. Before carrying out a swing, the following preparation is necessary.

(i) Check the compass for serviceability as described in para. 83.

(ii) Remove from the aircraft any magnetic objects not normally carried in flight, and liable to affect the compass. Ensure that no magnetic objects, liable to affect the compass, are carried by those engaged on the swing.

(iii) See that magnetic equipment, normally carried in flight and likely to affect the compass, is in position as far as possible. The flying controls, if near the compass, should be kept in level-flying position throughout the swing.

(iv) Take the aircraft to a compass base or some other level site removed from local magnetic disturbance.

42. On arrival at the selected site the swing may be carried out by the method given below. The aircraft's head must be within 5° of the magnetic heading detailed.

The Coefficient Method

First Phase

(a) Place the aircraft's head on magnetic North and note the Deviation.

(b) Place the aircraft's head on magnetic East and note the Deviation.

(c) Place the aircraft's head on magnetic South and note the Deviation. Calculate the coefficient C and correct it in the following manner:

Change the sign of C (since the aircraft is now heading South) and add it algebraically to the compass reading. This figure will be what the compass must read after correction. Now use the corrector device to make the compass read this figure. To do this with the micro-adjuster, insert the special key in one of the two control heads whose common axis lies at right-angles to the compass needle (in this case the port and starboard control heads) and turn gently in the appropriate direction until the required reading is obtained. Then remove the key. If using a corrector box, insert magnets athwartships until the required reading is obtained.

.../Example

Example

The compass of an aircraft reads 358° when the aircraft heading is 000°M. The Deviation is therefore +2°. When heading 180°M., the compass reads 182°. The Deviation is therefore -2°.

$$\text{Coefficient C} = \frac{(\text{Deviation on N} - \text{Deviation on S})}{2}$$

$$\text{Coefficient C} = \frac{(2^\circ - (-2^\circ))}{2} = \frac{+4^\circ}{2} = +2^\circ$$

While the aircraft is on Magnetic South, the coefficient C of +2° will be eliminated if the compass is made to read 182° - (+2°), namely, 180°.

(d) Place the aircraft's head on magnetic West and note the Deviation. Calculate coefficient B and correct it as for coefficient C, as follows:

Change the sign B (since the aircraft is now heading West) and add it algebraically to the compass reading. This figure will be what the compass must read after correction. Then use the corrector device to make the compass read this figure. To do this with the micro-adjuster, insert the special key in one of the two control heads whose common axis now lies at right angles to the compass needle (in this case the fore-and-aft control heads) and turn gently in the appropriate direction until the required reading is obtained. Then remove the key. If using a corrector box, insert magnets fore-and-aft until the required reading is obtained.

Example

The compass of an aircraft reads 093° when the aircraft heading is 090°M. The Deviation on East is therefore -3°. When heading 270° the compass reads 267°. The Deviation on West is therefore +3°.

$$\text{Coefficient B} = \frac{(\text{Deviation on E} - \text{Deviation on W})}{2}$$

$$= \frac{(-3^\circ - (+3^\circ))}{2} = \frac{-6^\circ}{2} = -3^\circ$$

While the aircraft is on magnetic West, the coefficient B of -3° will be eliminated if the compass is made to read 267° - (-3°), namely, 270°.

Second Phase

Conduct a check swing by placing the aircraft's head successively on the eight Cardinal and Quadrantal Points, and note the deviation on each.

Third Phase

(a) From these eight deviations, calculate coefficient A. Loosen the compass fixing screws, and remove A by rotating the whole compass that number of degrees in the appropriate direction (clock-wise if A is +, and vice-versa). Re-tighten the screws.

.../Coefficient A

Coefficient A should be corrected only if of the order of $1\frac{1}{2}^{0}$ or more and than only on the authority of the responsible navigation officer.

(b) Prepare and fit in the aircraft a Deviation Card of the remaining Deviations (See para. 44).

(c) Fill in the Compass Log Book.

Example

43. A Manchester aircraft is swung on the ground on April 1st, 1941. The following filled-in proforma shows the results of the first two Phases, as described in para. 42 (ii) for the stand-by compass.

After the Check Swing and the removal of coefficient A, the residual Deviations are found as tabulated in the bottom right-hand column of the proforma.

Date: 1.4.41.		Aircraft Type and No: Manchester X.2341 Compass Type and No: P.D. 521D.		
CORRECTING SWING				
(i) Approx. Course (M)	(ii) Actual Course (M)	(iii) Aircraft Compass reads	(iv) Deviation (ii)-(iii)	Coefficients
NORTH	359	003	- 4	C = $\frac{\text{Dev.on N-Dev.on S.}}{2}$
EAST	091	085	+ 6	
SOUTH	178	170	+ 8	
C (sign changed)		+ 6		= $\frac{-4 \ -8}{2}$ = $\frac{-6}{}$
Make Compass read		176		
WEST	267	265	+ 2	B = $\frac{\text{Dev. on E-Dev.on W.}}{2}$
B (sign changed)		- 2		
Make compass read		263		= $\frac{+ 6 \ -2}{2}$ = $\frac{+2}{}$

CHECK SWING					
(i) Approx. Course (M)	(ii) Actual Course (M)	(iii) Aircraft Compass reads	(iv) Deviation (ii) - (iii)	(v) Coefficient (A)	(vi) Residual Deviations (iv) - (v)
N.W.	317	316	+ 1	+ 3	- 2
NORTH	000	358	+ 2	+ 3	- 1
N.E.	047	042	+ 5	+ 3	+ 2
EAST	093	089	+ 4	+ 3	+ 1
S.E.	135	134	+ 1	+ 3	- 2
SOUTH	179	177	+ 2	+ 3	- 1
S.W.	225	220	+ 5	+ 3	+ 2
WEST	273	269	+ 4	+ 3	+ 1

Total + 24 ÷ 8 = + 3

.../Recording

Recording Deviation

44. The remaining Deviations referred to in Third Phase (b) above must be recorded for use in the air. For this purpose, Deviation Cards are provided for the use of the Pilot and the Navigator. They are placed in their appropriate holders near the compass position to which they refer. Owing to difficulty of applying the correct Deviation in flight, many Navigators keep a copy of the Deviation Card applicable to the Pilot's compass so that the Pilot only has to deal with Compass Courses during flight.

45. In practical Air Navigation, Deviation is always taken to the nearest degree. Thus, if the Deviation were + 1.3°, the value used would be + 1°, and so on. It follows that the headings where the Deviation has a value containing $\frac{1}{2}$° are in effect critical points, since on either side of them the Deviation is in practice one complete degree different. These critical headings are determined by drawing a graph of the residual Deviations in the space provided in the Compass Log Book (Form 343) and noting at what headings the graph cuts the half-degree lines.

46. By recording the critical headings and the Deviations that are applicable between them, the Pilot and Navigator are presented with Deviations in the simplest possible form. The Deviation Cards provided in the Royal Air Force are pictorial critical tables and require the minimum of effort to use.

47. Having made out the graph of the residual Deviations in the Compass Log Book (see figure 10), the compass adjuster should take the Deviation Card, and insert the value of the Deviations against the appropriate Magnetic headings.

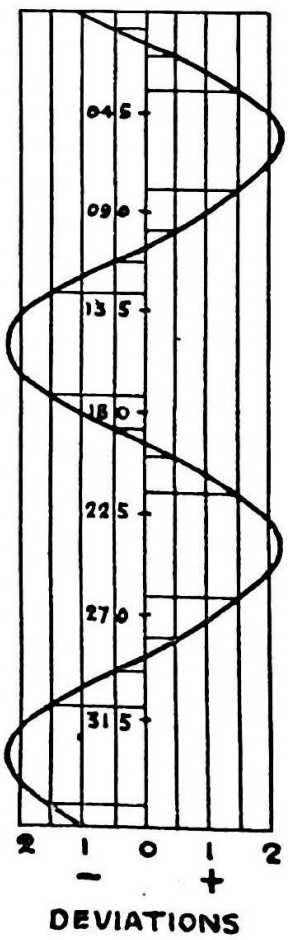
He should then draw four lines, radiating like spokes, to the headings, where the sign of the Deviation changes from positive to negative. The Card will then be divided into segments, and the work "ADD" should be plainly marked in the segments where Deviation is minus, and the work "SUBTRACT" in the segments where Deviation is plus. Thereafter the Deviation for any heading is onbvious from the Card at first glance. The particulars on the reverse side of the Form should then be completed, and the Card inserted in its proper holder. In this manner, the use of plus and minus signs is deliberately avoided in order to save any ambiguity.

Some Practical Aspects of Swinging

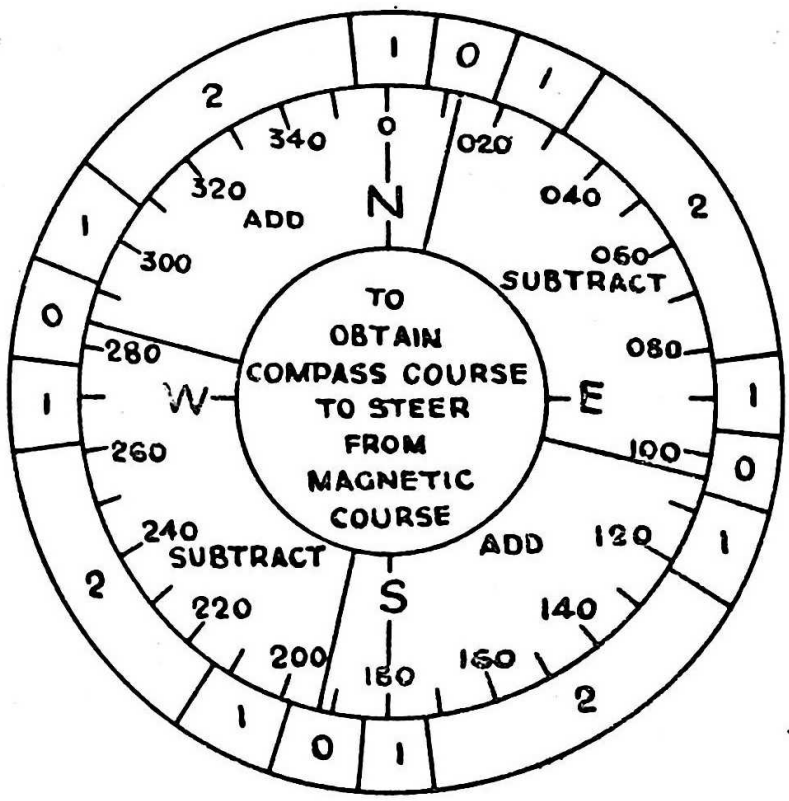
48. It frequently occurs, especially in the case of flying boats, that the only place available for swinging an aircraft is between or near hangers or in the vicinity of other objects likely to affect the direction of the Earth's magnetic field. If the distortion of the field is constant over the whole area utilised for the swing (including landing compass positions, if used), the swing will be just as satisfactory as when carried out in more favourable positions. It is, however, always inadvisable to swing aircraft inside hangars, over large masses of metal or in other places where the magnetisation of the aircraft's "soft" iron is likely to be affected.

49. A method of determining whether a doubtful site is satisfactory is as follows: Select some clearly visible object 3 - 4 miles distant so that its bearing is, for practical purposes, the same at all extremeties of the area, which, of course, need not be very extensive. Using a landing compass or other suitable bearing compass, take compass bearings of the object from various points on the site including the extremeties. If these bearings agree to within 1° of each other the site will be satisfactory.

.../If the



(a)



(b)

Fig. 10.

RECORDING DEVIATIONS.

50. If the direction of the Earth's field is found to vary over the area, i.e., if the compass bearings referred to in paragraphs 49 do not agree, it may still be used, provided that the aircraft is swung in one spot around an imaginary axis vertically through the compass, and that the landing compass method of swinging is not employed. The following procedure should be adopted:

(i) Before the swing, use some convenient form of bearing compass to measure the magnetic bearing of a distant object from the position that will be occupied by the aircraft compass during the swing.

(ii) Put the aircraft on the approximate required heading by means of the Pilot's compass. Measure the relative bearing (0^{o} - 360^{o}) of the distance object from the aircraft's head, by means of an 0.2 compass, a Bearing Plate, or a Marine-type sextant.

(iii) Obtain the Magnetic heading of the aircraft from the formula: Magnetic Heading = Magnetic Bearing of Object + (360^{o} - Releative Bearing), - 360^{o} if necessary.

(iv) Compare the compass Course of the aircraft with the magnetic heading, (iii). Any difference will be the amount of Deviation of the compass on that heading. Its sign will be "+" if the compass Course is less than the Magnetic heading, (iii) and vice versa.

(v) Repeat the process as necessary for the completion of the swing.

For a quick method of obtaining the magnetic heading of the aircraft, an Astro-compass may be employed. This instrument avoids the calculations necessary when relative bearings are used.

Swinging of Aircraft Afloat

51. Compasses should never be corrected when the aircraft is afloat owing to the difficulty of keeping the heading steady. It may occasionally be necessary, however, to carry out a check swing on the water. Calm water and no appreciable wind are essential.

52. The main problem is to determine the correct magnetic heading of the aircraft at a given moment. The Astro-compass is the best instrument for this purpose. If the Sun is visible, the True headings of the aircraft may be found. The required Magnetic headings are obtained by applying the local Variation. Should the Sun be obscured, a distant object whose Magnetic bearing is known can be used.

53. Whether using the Sun or a distant object the procedure would be as follows:-

(i) Steady the aircraft approximately on the heading required. When absolutely steady, note the Course indicated by the Astro-compass and aircraft compass simultaneously. Two observers with some signal pre-arranged between them are essential for this. The difference between the two headings will be the Deviation of the compass. When using instruments giving relative bearings of distant course simultaneously. Thereafter proceed as in para. 80 (iii) and (iv).

(ii) Repeat the process on as many headings as practicable throughout the 360^{o}. At least eight headings are essential. If possible the headings should be on the cardinal and quadrantal points.

.../(iii)

(iii) A graph of the Deviations obtained should then be constructed, and the necessary information to prepare a Deviation Card extracted from it.

Objections to Swinging on the Ground

54. The Deviations obtained from the swinging of aircraft on the ground will correspond only in very few cases to those obtaining in cruising flight. The main reasons for this are as follows:-

(i) Component R.

As has been mentioned elsewhere, component R is the vertical component of the aircraft's permanent magnetism. It can be represented by a single magnet, perpendicular to the plane of the aircraft, and whose axis passes through the centre of the magnet system of the compass. In the case of aircraft built in the Northern magnetic hemisphere, this magnet will have its blue pole uppermost.

When the aircraft is in the level cruising position, R. will have no effect upon the compass, as can be understood from Figures 19 (a) and (b).

Normally, however, the aircraft when on the ground will be tail-down by a number of degrees depending upon the type in question. The R magnet will also be tilted from the vertical through the same angle, and its lower pole thereby displaced horizontally from the centre of the compass (See Figure 20).

The Pole will thus exert a horizontal force upon the compass needle in the fore-and-aft line. The effect on the needle will be similar to that due to component P, Deviation being maximum on East and West, and zero on North and South.

Deviation due to R, non-existent in level flight, will, therefore, be erroneously included in the calculation and subsequent correction of coefficient B.

Note:

It is possible to neutralise component R with vertical permanent magnets. A type of corrector has been designed for this purpose

(ii) Under-carriage Retraction

The difference in position between an under-carriage when extended and when retracted may change considerably its effect upon the compass.

Since under-carriages are normally extended during swinging on the ground, the Deviations observed during the swing will not apply when the under-carriage is retracted as in flight.

Various systems of jacks and turntables have been suggested to permit aircraft to be swung on the ground in flying position and with undercarriage retracted. In the case of all but very light aircraft, however, such apparatus would have to be too massive and elaborate to be a practical proposition.

55. The use of engines for ground swings is prohibited, as long periods of idling, especially in warm weather, are detrimental to the engines.

In the case of small aircraft, man-handling is sufficient; but where aircraft are too big for this it will be necessary to use a tractor.

.../However

However, since only when in flight are cruising conditions fully represented (Engines running, controls correctly positioned, tail in flying attitude), it is recommended that check swings, astro-compass be conducted whenever weather permits, and the aircraft is suitably equipped.

Swinging Aircraft in the Air

56. The disadvantages and inaccuracies of ground swinging are all avoided when the aircraft is swung in flight. With the Astro-compass, described in para. 85 et seq., the process is easy and quick.

The practical requirements are:-

(i) Calm air conditions.

(ii) A visible Sun whose altitude is preferably less than 45°.

(iii) Sufficient view of the ground to permit pin-pointing of the aircraft.

(iv) Positions for the Astro-compass in the aircraft which provide an adequate view of the Sun on all the cardinal and quadrantal Courses.

(v) A watch keeping G.M.T.

(vi) One Navigator in addition to the Pilot.

(vii) Automatic Controls.

Procedure for Swinging in the Air

57. Assuming that it is required to swing the Pilot's compass in a certain aircraft, the following procedure is recommended.

(i) From the Air Almanac prepare a graph of G.M.T. against L.H.A. Sun at a selected position A, for a period covering that during which the swing is to take place. This graph is simply drawn as a straight line between the values of L.H.A. Sun for the G.M.T's. of the start and finish of the swing.

(ii) Prepare the aircraft for swinging as described in para. 41.

(iii) Take off and using automatic controls, fly straight and level at normal cruising speed over point A on a compass Course of 000° (See figure 21). Apply local Variation to obtain the Magnetic Course and thence the Deviation of the Pilot's compass. The mean of a number of Astro-compass readings should be taken.

(iv) Repeat the above procedure on compass Courses of S, E and W, flying according to Figure 21. For greatest saving of time, the Courses should be flown in the order given, e.g. 1, 2, 3, and 4. The Courses shown are Magnetic, and the aircraft should be steered within 5° of them. Keep always within 10 miles of point A.

(v) Land and calculate coefficients B and C.

(vi) Place the aircraft's head on S by compass and remove coefficient C.

Example

(Coefficient C	= +4°)
Aircraft's head by compass	= 180°
C, with sign changed	= -4°
∴ make compass read	176° (with micro-adjustor or magnets).

(vii) Place the aircraft's head on W by compass and remove coefficient B.

(Coefficient B	=	-3°)
Aircraft's head by compass	=	270°
B, with sign changed	=	$+3^{\circ}$
.°. make compass read		273° (with micro-adjuster or magnets)

(viii) Take off and, using the Astro-compass as before, carry out a Check Swing on the 8 cardinal and quadrantal compass Courses, flying according to Figure 22. Again, to save time, fly in the order shown, keeping within 5° of the illustrated Magnetic Courses and within 10 miles of point A.

(ix) Land. Calculate and correct for coefficient A. Prepare a Deviation Card and fill in the Compass Log Book in the usual manner.

Note: If time does not permit steps (i) - (iv) above of the Correcting Swing being done in the air, they may be done before flight. The same accuracy of correction, however, cannot always be expected if B and C are calculated from Deviations obtained on the ground.

Change of Deviation during Flight

58. Deviation of the compass may change during flight, and differ from that shown on the Deviation Card owing to any of the following causes:

(i) Change of magnetic latitude. (See para. 65(i)).

(ii) Change of bomb load.

(iii) Continuous vibration of the aircraft.

(iv) Continuous operation of electrical circuits.

(v) Electrical storms encountered.

It is, therefore, essential to check the compass Course during flight as frequently as possible. The Astro-compass should be used to obtain the actual True Course of the aircraft. If this does not agree with the required True Course, the compass Course being steered should be altered accordingly. The mean of a number of Astro-compass readings should be taken at each check.

Acceleration and Deceleration Errors of the Magnetic Compass

59. These errors, which are transient, are better described is temporary misbehaviour of the compass. They occur during changes of Course and speed, and produce the worst results, from the Pilot's point of view, when turning on northerly Courses in the Northern hemisphere and on southerly Courses in the Southern hemisphere. Their cause and effects form the subject of the ensuing paragraphs.

60. A pendulum suspended in an aircraft will, as long as a constant course and speed are maintained, remain for practical purposes in the true vertical, with its centre of gravity directly below the pivot of point of suspension. If, however, the aircraft turns, accelerates or decelerates, the pendulum will cease to be vertical. This is because, owing to its inertia, the centre of gravity will lag relative to the pivot and thus move from the normal position vertically below it. In the case of properly-banked turns, the forces acting on its centre of gravity will cause the pendulum to remain perpendicular to the plane of the aircraft and to take up an angle to the true vertical equal to the angle of bank.

.../Since turns

Since turns themselves are, in effect, accelerations towards their centres and, whether properly-banked, under-or over-banked, always cause a pendulum to take up a false vertical, the subject may be summed up broadly by stating that any accelerations or decelerations undergone by an aircraft during flight will cause the centre of gravity of a pendulum suspended therein to be deflected from its normal position vertically below the pivot.

61. The magnet system of a compass, to satisfy its requirements, must operate as nearly horizontal as possible. To achieve this, the vertical component, Z, of the Earth's field must, in the Northern hemisphere be prevented from pulling the red end of the compass needle downwards towards the North Magnetic Pole, and, in the Southern hemisphere, be prevented from pulling the blue end of the needle downwards towards the South Magnetic Pole.

This is done by pivoting the magnetic system at a point symmetrically vertical above its centre of gravity. The system is thus made pendulous, the moment of the couple between the centre of gravity and the pivot being sufficient to reduce the dip of the needle in those latitudes from 67° to 2°.

62. The couple can have its maximum effect only when the centre of gravity is, with the pivot, in the plane of the local meridian. (The local magnetic meridian is taken as that passing through the pivot). If, for any reason, the centre of gravity is deflected from the plane of the local magnetic meridian, the couple can no longer have its full effect in opposing the Earth's vertical force, and the red end of the compass needle will be free to dip. This will result in a rotary movement of the needle. (See Figure 11) (in the Southern hemisphere the blue end of the needle will be the one affected).

63. Since the magnet system of a compass is pendulous, it behaves like a pendulum in an aircraft. Any acceleration or deceleration in flight results in a displacement of the centre of gravity of the system from its position beneath the pivot. As long as both pivot and centre of gravity remain in the plane of the magnetic meridian, the compass needle will merely vary in dip without any rotary movement about its pivot.

If, however, the centre of gravity is displaced in any other direction relative to the pivot, the needle will rotate. The rotation will be greatest for a given angle of displacement when the displacement is in the magnetic East or West direction. (See figure 11).

64. Maximum East or West displacement of the centre of gravity is produced by a change of Course on North and South headings, and by a change of speed on East and West headings. An example of each is described for the Northern magnetic hemisphere:

(i) If a properly-banked turn be made from North to East, the magnet system will take up the same angle of bank as the aircraft. The centre of gravity will thuse be displaced to the West of the pivot and out of the plane of the local magnetic meridian. More freedom to dip will be permitted, and a rotation of the needle in a clockwise direction will result. (See Figure 23). The aircraft is also turning clockwise, so that, if both it and the needle are rotating at the same angular speed, the compass will not indicate any turn at all.

If the aircraft is turning more slowly than the needle, an apparent turn towards North, instead of away from it, will be indicated.

.../If the

If the aircraft turns faster than the needle, an apparent turn less than the true turn will be indicated.

When turning towards the West from the North, the centre of gravity will be deflected to the East, and identical effects will be observed.

On Southerly headings, a change of Course to the East or West, will result in a rotation of the compass needle in the opposite direction. Exaggerated indications of turn will therefore be given.

(ii) If the aircraft's speed be increased when flying on an Easterly Course, the acceleration will be applied to the pivot of the magnet system. The centre of gravity of the system will, by virtue of its inertia, lag behind the pivot until constant speed is again resumed. This will result in a displacement of the centre of gravity to the West of the pivot, and a clockwise rotation of the needle.

Thus, although the aircraft may have maintained a straight Course, the compass will, while the speed is increasing, indicate as apparent turn towards the North.

Reduction of speed will similarly produce an apparent turn towards the South.

On Westerly headings changes of speed will also produce an apparent turn towards North for increase in speed and towards South for decrease in speed, although the rotation of the needle will be in the opposite direction to that for Easterly readings.

Other Causes of Deviation or Change of Deviation

65.

(i) Changes of Magnetic Latitude

As Magnetic Latitude changes, the values of H and Z also changes.

Change of H is important only in the sense that the directive strength of a compass needle changes with it. The greater H is, the greater will be the directive strength of the compass needle and the less, therefore, will be the Deviation caused by local magnetic disturbance.

This stresses the additional importance of accurate swinging in the case of aircraft required to travel long distances, involving much change of magnetic Latitude. Any residual "hard" iron Deviation, due to inaccurate correction of B or C, will become greater in its effect with any decrease of H, and less with any increase of H. This change in Deviation can be sufficient to cause appreciable errors in the Courses steered.

With change of Z, the strength of vertical "soft" iron magnetism will alter and the Deviation due to it will vary accordingly. The effect will be aggravated by the fact that any increase in Z is always accompanied by a corresponding decrease in H. Consequently a stronger vertical "soft" iron component will be acting on a compass needle of reduced directive strength. Thus an aircraft compass, though accurately swung to begin with, may show quite appreciable Deviation if it undergoes much change of Magnetic Latitude. The regulation contained in K.R. and A.C.I. para. 762 should be complied with in this respect.

.../(ii)

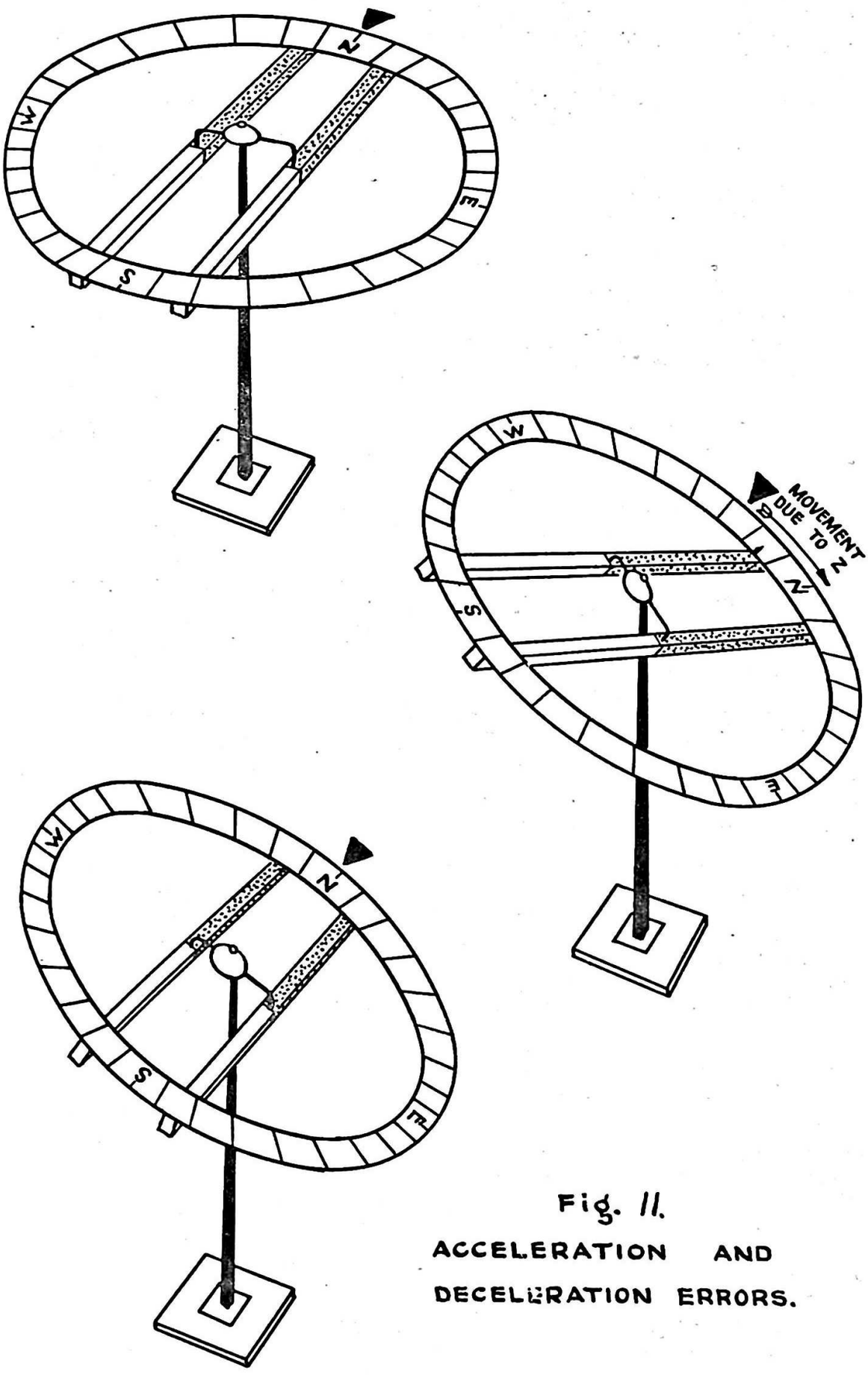


Fig. 11.

ACCELERATION AND DECELERATION ERRORS.

(ii) Electrical effects

It has been explained elsewhere that electric currents, whether passing in a single wire or a coil, can produce a magnetic field. In aircraft, provided that the regulation "safe distances" for electrical components have been complied with, no appreciable Deviation due to such causes should be experienced.

It sometimes happens, however, that stray wires carrying direct current find their way into the vicinity of the compass, or that electrical apparatus, such as engine revolution-counters, become magnetically energised in an unspecified manner. Such possible sources of Deviation should be tested as to their effect upon the compass during swinging.

In the case of engine revolution-counters, the only reliable test occurs where the aircraft is swung during cruising flight. Any Deviation caused thereby will be automatically dealt with during the swing.

CONSTRUCTION AND MAINTENANCE OF COMPASSES

66. Detailed construction of the different types of compass used in the Royal Air Force is given in A.P. 1743. It is intended here to deal with the subject only in a general way, in order to assist those responsible for the care and maintenance of the instruments.

MAGNETIC COMPASSES

67. The most common types of magnetic compass in use are the P.6 and P.4. The construction of both is very similar, the main difference between them being in their relative sizes. The smaller P.6. compass is used here for illustrative purposes.

68. The principal component of any compass is the magnet system. This consists of a number of small permanent magnets (2 in the case of the P.6) fixed parallel to each other and freely pivoted at a point above their common centre of gravity (A in Figure 26).

69. Magnet system and pivot are contained in a bowl filled with liquid. The liquid is a mixture of alcohol and water. Its main purpose is to damp the movement of the magnet system and render it dead-beat[52] (or aperiodic) in action. It also lessens the effective weight of the magnet system by displacement and thereby saves wear at the pivot.

70. Attached to the magnet system are a number of projecting "damping" wires (Figure 26) the purpose of which is to assist in damping the movement of the system by offering resistance to the liquid. The damping wires are used to define the cardinal and quadrantal points. The N, S, E and W wires carry minute glass tubes containing a luminous compound to make them visible by both night and day. The N-wire carries a distinguishing cross-piece (C in Figure 26).

71. The liquid is kept in the bowl by a glass top. This is maintained in position and hermetically sealed by means of a brass verger ring (B in Figure 26) and rubber washer. Expansion and contraction of the liquid is allowed for by an expansion device fitted in the underside of the bowl.

[52] If after deflection a compass needle returns to rest without appreciable over-swinging, it is said to be "dead-beat" in action.

.../Resting on

Resting on the verge ring, and free to rotate round it, is the grid ring (Figure 25). This is graduated in the same manner as a compass card, luminised as necessary, and can be correctly oriented relative to the magnet system by means of parallel luminous grid wires (H in Figure 25). Its purpose is two-fold. First, it avoids the necessity of attaching a compass card to the magnet system itself, thereby improving the performance of the latter; second, it makes accurate steering easier, the Pilot merely having to keep the grid wires parallel to the N-S damping wire to maintain a required Course. The Course to be steered is pre-set by rotating the grid ring until the required number appears against the lubber line attached to the inside of the bowl (C in Figure 26). The grid ring may be secured in position by means of a clamping device (D in Figure 26).

73. The bowl assembly is placed in a container (Figure 27) and rests on four equally-spaced, helical bronze springs (I in Figure 27). In older compasses rubber pads were used instead of springs. The springs take the entire weight of the bowl and thereby insulate it from vibration. By means of a device known as a floating ring (J in Figure 27), the bowl is prevented from turning inside the container, but is permitted limited movement in all other directions. Lateral movement is damped by the frictional action of leaf springs, one of which is shown at E in figure 26.

74. The bowl is prevented from leaving the container by means of the lid ring (K in Figure 27). The lid ring overlaps cork-surfaced projections attached to the bowl (F in Figure 26). For convenience of assembly, the lid ring is in two halves.

75. Three drilled lugs are fitted to the bottom of the container for securing the compass to the aircraft. One of these (L in Figure 27) is graduated in degrees to give adjustment for coefficient A.

Installation of Magnetic Compasses

76. Compasses must never be fitted in aircraft in positions other than those officially specified. Such positions have been carefully selected so as to satisfy magnetic and other requirements. Service Units in general, however, will never have to approve the choice of final installation but will merely have to replace compasses already installed.

77. A new compass should be positioned so that the adjustment scale for coefficient A has equal movement in either direction. Brass or other non-magnetic screws should be used to secure the compass.

78. As a precaution, the micro-adjuster should be set to the neutral position before a new compass is adjusted for the first time. This may be achieved by rotating each pair of control heads through their maximum movement, counting the number of key turns required for this, and then turning back through half that number of turns.

Installation of Micro-Adjusters

79. Micro-Adjusters are usually secured to aircraft independently of the Compass. They should be fitted in the approved position with securing lugs nearest to the compass and with their centres vertically below the centre of the compass.

80. If the effect of a micro-adjuster is found to be too powerful for accurate adjustment, non-magnetic washers or distance-pieces may be used to increase its distance from the compass.

81. Compasses and micro-adjusters are always marked so as to indicate which point around their circumference is Aft, and which Forward. They should always be installed with regard to such marks.

.../If broken

Care and Maintenance of Magnetic Compasses

82. If broken or damaged parts need replacement, or the compass fails to satisfy the requirements given in para. 83, the compass should be classed unserviceable and returned to the Admiralty Compass Observatory through the usual channels. A defect report should be included.

83. Compasses should always be kept at the highest possible state of efficiency. To ensure this, the following procedure should be complied with before each swing :

(i) Inspect the compass for traces of oil or petrol. These substances affect the luminosity of the grid ring and wires, obliterate graduations and attack rubber components.

(ii) Inspect the liquid for discolouration. This will usually appear as a darkening of the damping-wire luminising compound. Discolouration may be due to the presence of sediment formed by corrosion. This sediment may settle when the aircraft is stationary and appear only in flight. If discolouration is sufficient to affect the accurate reading of the compass by day or night, the instrument is unserviceable.

(iii) Inspect the liquid for bubbles. If any are present, the instrument is unserviceable. Bubbles may only appear at heights where the outside and atmospheric pressure is low. If their presence under these conditions is observed, the instrument is unserviceable.

(iv) Move the compass bowl gently in all directions (except in azimuth) and ensure that no metallic contact occurs between it and the aircraft or container. Ensure that the spring or rubber vibration insulators are functioning correctly. If not, the instrument is unserviceable.

(v) Test the grid ring for freedom of rotation. If the movement is too slack, and accurate setting difficult for this reason, the instrument is unserviceable. If the movement is too stiff, the instrument is unserviceable.

(vi) Test the clamping device for efficiency, it should be slightly past the vertical position when the grid ring is properly clamped.

AT ALL TIMES KEEP COMPASSES AS CLEAN AND DRY AS POSSIBLE.

Pivot Friction

84. If the action of the magnet system of a compass becomes sluggish or erratic, it should be tested for excessive pivot friction. To do this, remove the compass from the aircraft and level it. The magnet system should then be deflected through ten degrees by placing a piece of magnetic material near it, and should be held in this position for half a minute to allow the liquid to come to rest. It should then be released and the reading at which it settles carefully noted, no tapping or vibration being applied while it settles. The deflection is then repeated in the other direction and the settling position again noted. The difference between the two settling positions should not exceed 2°, but a compass may be considered serviceable if light tapping of the compass bowl will bring the difference of readings within this limit.

.../The Astro

THE ASTRO - COMPASS

85. The Astro-compass (see figures 28 and 29) consists of a Bearing Plate (1) with a moveable Sighting Device (2) attached to it. The Sighting Device is set relative to the Bearing Plate so that the angle between its line of sight and a north-mark on the Plate is equal to the Azimuth of an observed Heavenly Body.

Now the Azimuth of a Heavenly Body depends on three factors, viz;

(i) The local Hour Angle of the Body (3);

(ii) Its Declination (4);

(iii) The Latitude of the observer (5).

The instrument is so constructed that when these values are set on the Astro-compass (the scale for each being clearly marked), and the Sighting Device is aligned on the Body, the Bearing Plate will be properly oriented and the north-mark upon it will indicate True North.

Construction

86. The Astro-compass fits into an 0.5 or 0.5A compass standard and may be levelled by means of Cross-levels (6) and Adjusting Screws (7).

Its base consists of a Bearing Plate (1), free to rotate against a Lubber Line (8). Two graduated Hour Angle Scales are mounted above, one in white (3a) for North Latitudes and one in red (3b) for South Latitudes. These scales are locked togehter and are rotated by a spring-loaded Knob (9).

Attached to the top of the Hour Angle is a Sighting Device (2), which has a shadow bar and screen for use with the Sun or Moon and a prismatic star-sight for use on other occasions. Although aligned permanently with the 0° - 180° line of the Hour Angle Scales, the sights can be tilted for any Declination between 64°N or S. The Declination is read against an arc (4), engraved in white (for North Latitudes) or red (for South Latitudes).

The Latitude Scale (5), white for North and red for South, is adjusted by a knob that indicates single degrees to be added to the tens of degrees marked on the Scale screen.

87. When using the Sun or a bright Moon, the Bearing Plate is rotated until the shadow from the shadow bar falls between the parallel lines on the shadow screen.

If the Heavenly Body in use cannot be sighted exactly at the imaginary intersection of the two white lines of the foresight, ensure that the sights are set so that the Body is vertically above or below the point of intersection. (See figure 30).

.....

ELECTRICAL & INSTRUMENT SECTION

HENLOW DIVISION, R.A.F. TECHNICAL COLLEGE

GYRO GUN SIGHT MK. IIC.& D.

Instrument Precis No. 4.

General

Mk.IIC is a predictor sight, for use in power turrets, Mk.IID for use in fighters. All the air gunner has to do is to keep his sight on the target and the sight makes all allowances for -

(1) Gravity drop.

(2) Azimuth Trial and Elevation trail of the bullet.

(3) Enemy speed.

Mk.IIC is a reflector sight as distinct from a prismatic sight and hence can be used by night as well as by day.

In addition to the predictor sight, it also incorporates a non-predictable sight which is provided for harmonisation and maintenance checks, and may also be used as a stand by in the event of the predictor sight failing.

Allowances to be made:

(1) Gravity drop

Due to effect of Gravity on the bullet, has three deciding factors.

(a) Increased range of target, increase allowance.

(b) Position of guns, allowance maximum when horizontal, minimum when vertical.

(c) Calibre of shell, .5 fastest,decrease allowance; 20mm increase allowance, .303 slowest, most allowance.

(2) Azimuth Trail

Governed by five factors.

(a) Air Speed - increased airspeed, increase allowance.

(b) Range - increased range - increase allowance.

(c) Height - increased height, decrease allowance.

(d) Calibre - as for gravity drop.

(e) Position of Guns - maximum when guns are on beams - minimum when fore and aft.

(3) Elevation Trail

Also governed by five factors.

.../(a)

(a) Air Speed - increased airspeed - increased allowance.

(b) Range - increased range - increased allowance.

(c) Height - increased height - decreased allowance.

(d) Calibre - as for Gravity drop and Azimuth Trail.

(e) Position of guns-maximum when guns are elevated as or depressed, minimum when horizontal.

N.B. When the guns are elevated in azimuth, maximum allowance on fore and aft line, minimum on the beam.

(4) Enemy Speed

(Gyro Lag) - Governed by four factors.

(a) Rate of turn of the turret - increased rate of turn will give increased allowance.

(b) Increased range - gives increased allowance.

(c) Height - increased height - decreased allowance.

(d) Calibre - as for other allowances.

Optical System

Predictor sight has two opaque discs with clear lines engraved to give a circle of diamonds the diameter of which is variable.

Illuminated by 22V lamp - image thrown on to Gyro mirror with alluminised surface. The mirror is driven by an electric motor by means of spring drive. The motor speed is 5000 R.P.M. controlled by a governer with resistance in series with field circuit. Gear ratio 5-3. Speed of mirror 2800 - 3000 R.P.M. Maintained on Hooks coupling. Image thrown on to fixed mirror reflected through collimating lens to reflected glass.

Gyro Motors

(i) 22V Series Wound - 5000 R.P.M. ± 500 R.P.M.

(ii) Speed governed by centrifugal governer coming into operation when speed increases bringing a resistance in Series with the armature windings thus slowing the motor down to within its correct speed.

Gyro Mirror

Driven by a double coil spring belt from the motor at 2800 - 2000 R.P.M.

Hooks Coupling

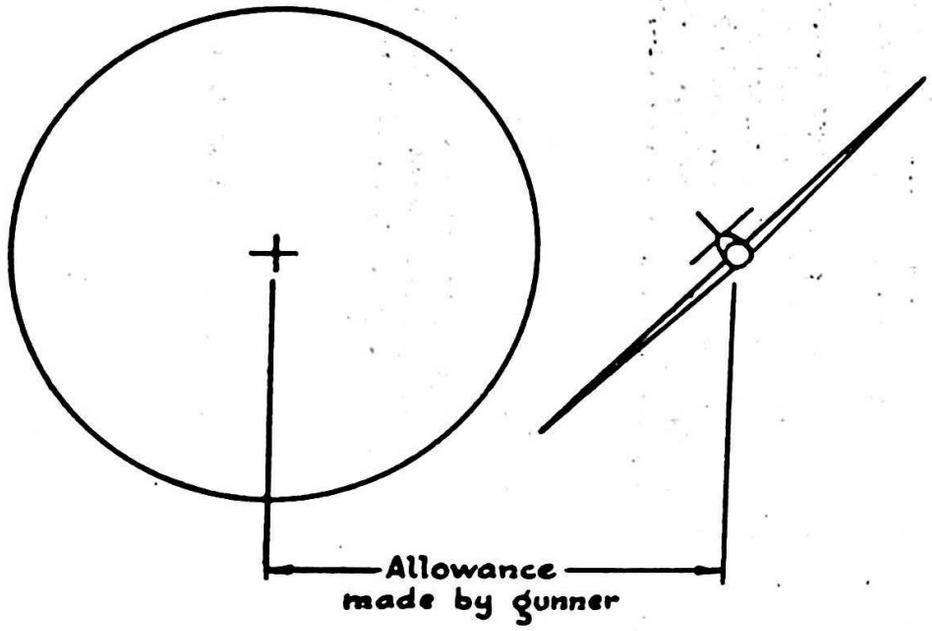
Gives Gyro Mirror freedom to spin, tilt and veer.

Precession of gyro by pot magnets.

(1) Centre of dome precesses towards the energised or stronger magnet.

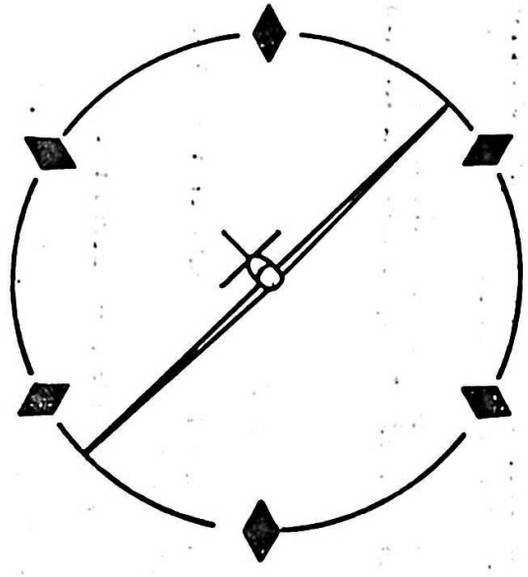
(2) Changing polarity has no effect on direction of precession.

.../(3)



NON-PREDICTOR SIGHT

A.



PREDICTOR SIGHT

B

Fig. 1.

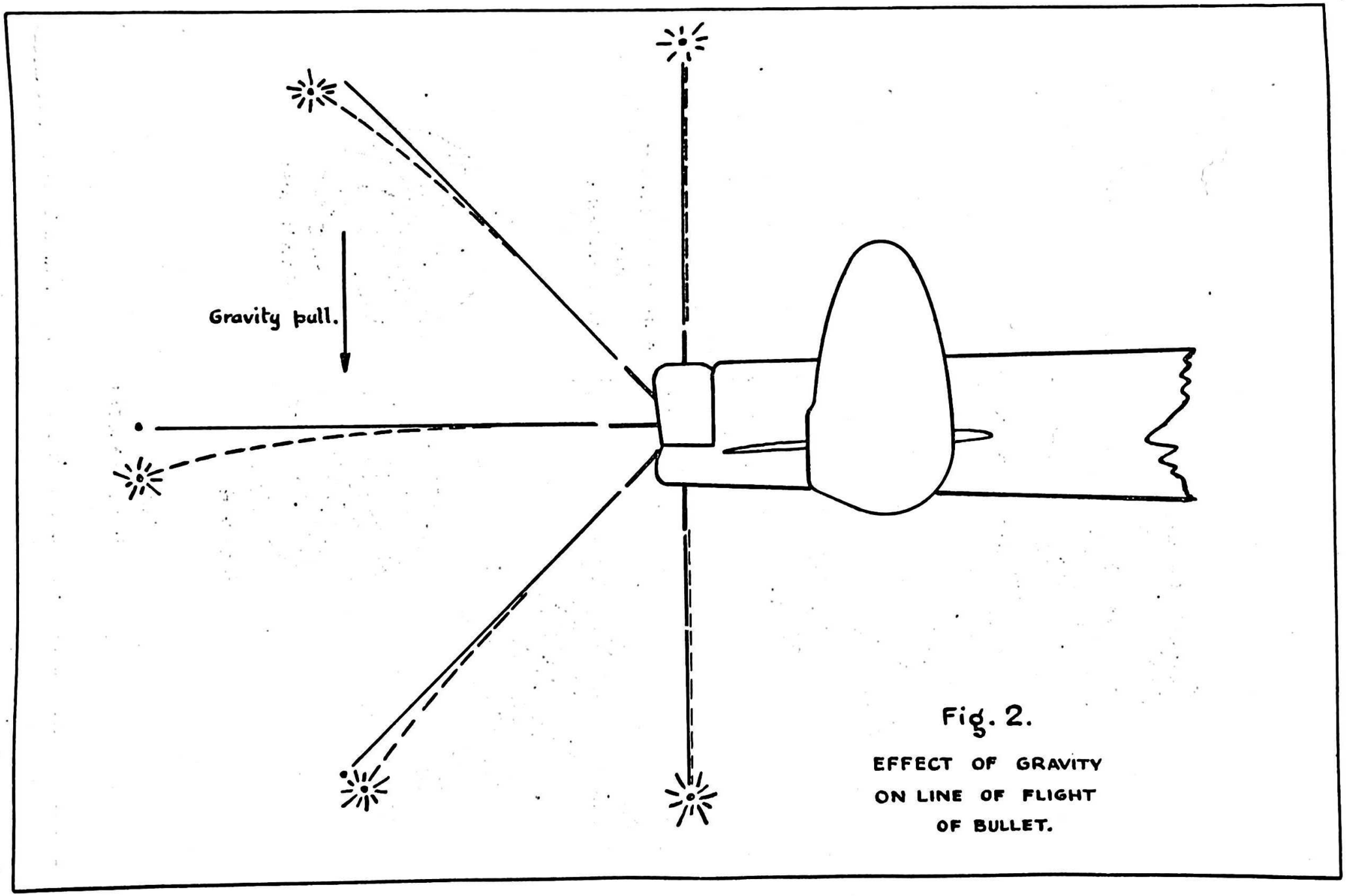


Fig. 2.

EFFECT OF GRAVITY ON LINE OF FLIGHT OF BULLET.

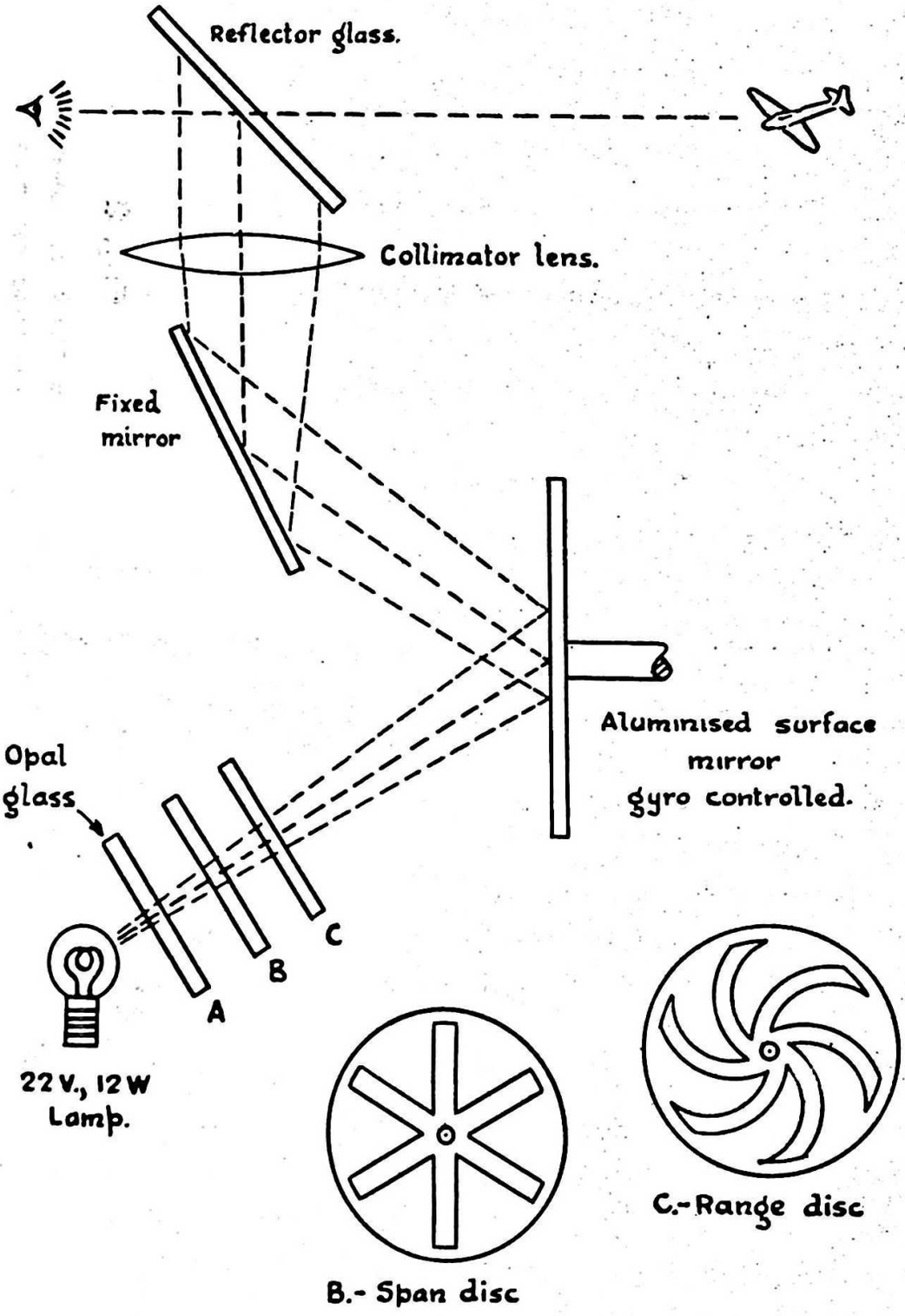


Fig. 5
OPTICAL SYSTEM.

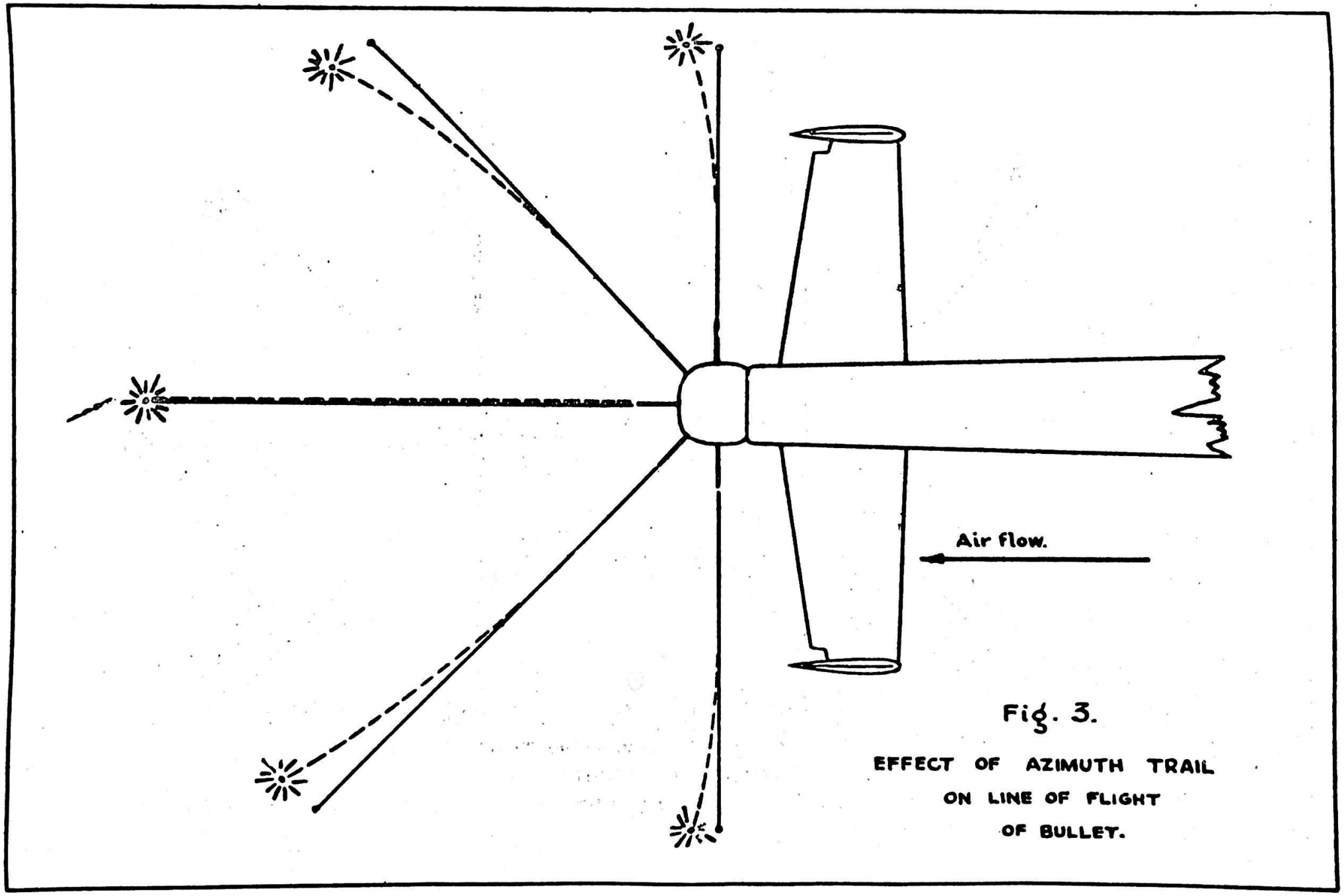


Fig. 3.

EFFECT OF AZIMUTH TRAIL
ON LINE OF FLIGHT
OF BULLET.

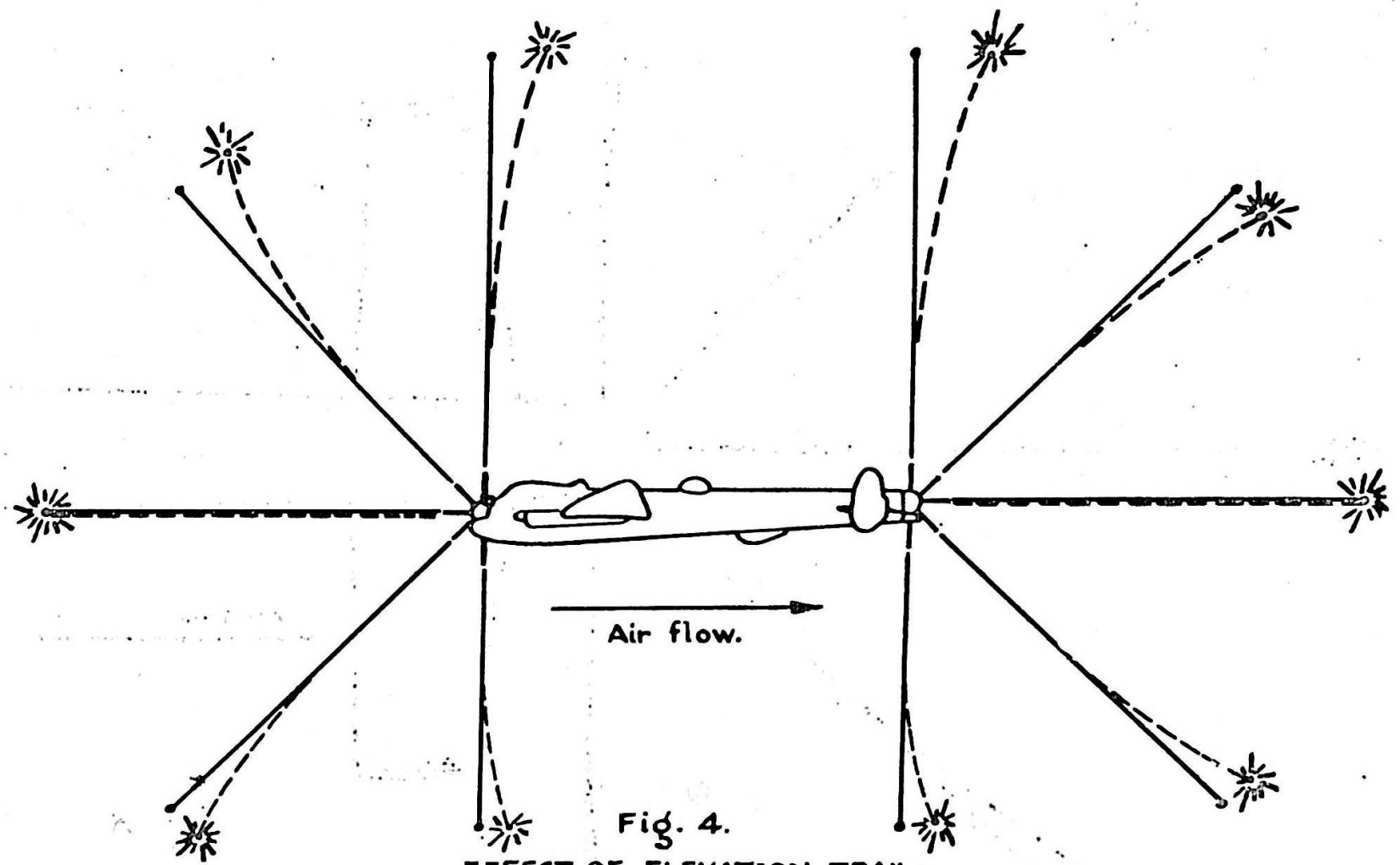


Fig. 4.

EFFECT OF ELEVATION TRAIL ON LINE OF FLIGHT OF BULLET.

(3) Change in direction of Rotation has no effect on direction of precession.

(4) With increased height - conductance of dome increases. Rate of precession increased.

Enemy Speed Allowance (Gyro Lag)

When the Guns are following a moving target, a relative movement takes place between the magnets and the Gyro Dome. Thus one magnet becomes further from the centre than the opposite one, and so exerts a greater torque. The gyro will once again precess towards the central position, which will however only be reached when the guns are stationary with zero I.A.S.

Differences between Mk.IIC & Mk.IID Series I.

The latter has:-

(1) No anti-vibration mountings.

(2) Range pulley not spring loaded (Double cable to Range control).

(3) Azimuth and Elevation trail coils are connected inside the sight but not between junction box and ten pin plug (No trail allowance and therefore no I.A.S., Azimuth or Elevation control).

(4) No. height control - this would mainly be required for temp. compensation. Temperature change in cockpit however is not as great as in a turret.

(5) Gravity drop half that for Mk.IIC.

(6) Ranging knob attached to throttle lever and Range control cable so connected that pushing throttle forward automatically reduces range. Throttle lever pulley gives anticlockwise rotation which is changed to clockwise rotation to the range control.

.....

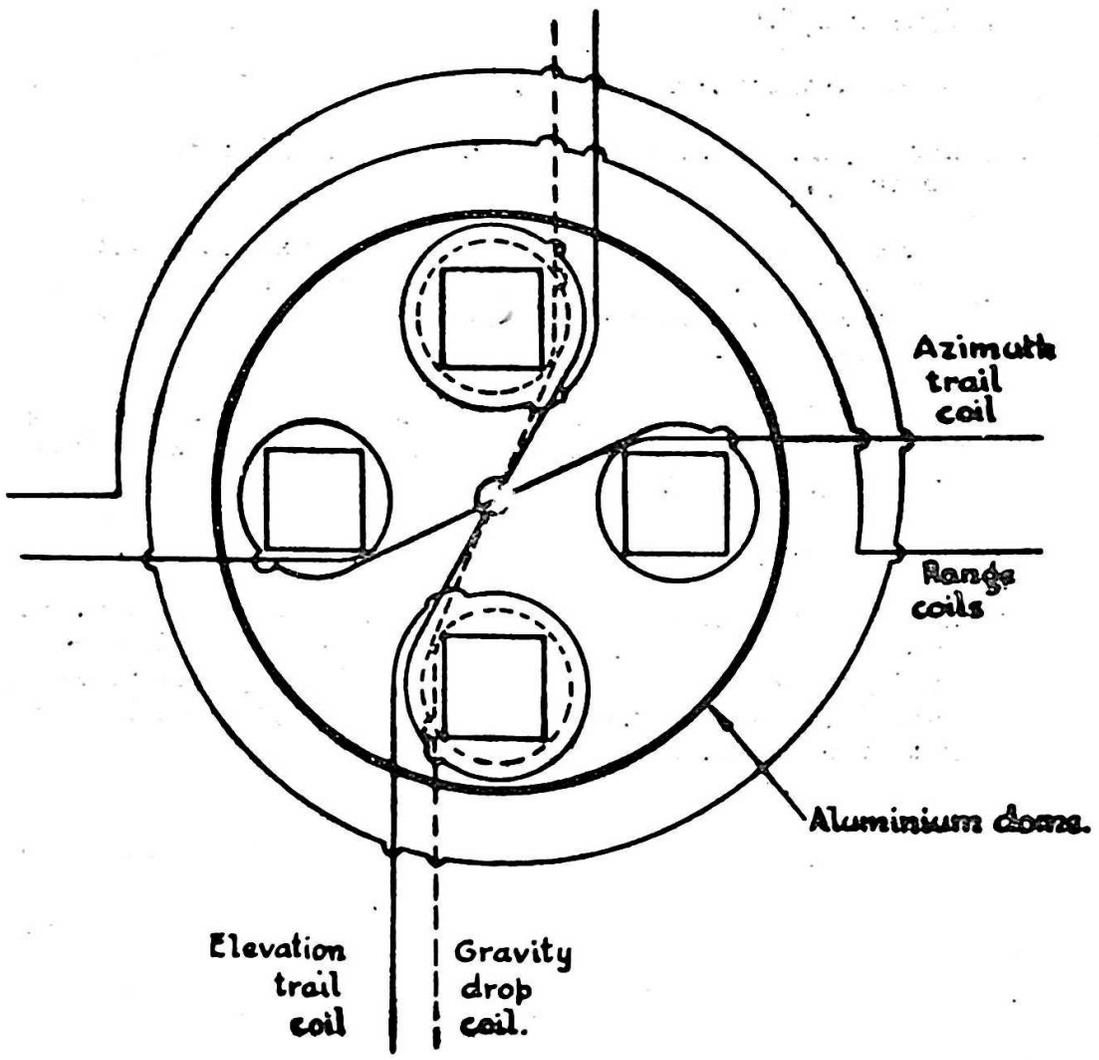


Fig. 6.

CONTROL OF DOME FOR ALLOWANCES.

ELECTRICAL & INSTRUMENT SECTION

HENLOW DIVISION, R.A.F. TECHNICAL COLLEGE

O X Y G E N

Instrument Precis No. 5.

Lecture I

Introduction to Oxygen

Oxygen is necessary to life.

This oxygen is obtained from the air which we breathe in. Air consists of approximately 80% nitrogen and 20% oxygen. (Small properties of several other gases).

Nitrogen is an inert gas, serves only to dilute the oxygen.

At all altitudes the proportion of nitrogen to oxygen in the air remains constant.

The density of each though will decrease with an increase in altitude.

At sea level the air pressure is greater than at say, 15,000 ft. Therefore the air is compressed and if the pressure is decreased, as it is at 15,000 ft. then the air will expand (Boyle's Law). The same quantity of air will therefore encompass a larger value, and the quantity of oxygen per unit volume will have decreased.

The capacity of a man's lungs is approximately 1½ litres.

So it can be seen that if a man inhales 1½ litres of air at sea level, he will breathe in far more oxygen than if he inhales 1½ litres at 15,000 ft.

In actual fact, then we can say that it is the pressure of the atmosphere which governs the amount of oxygen which we breathe in.

If this pressure drops, then the amount of oxygen taken in by each inhalation is insufficient to supply the needs of the body.

What happens to the oxygen after is has passed into the lungs? To start with it is forced by the atmospheric pressure into the blood as it passes through the lung walls. The blood then carries the oxygen to those parts of the body where it is needed.

If then there is insufficient oxygen in the blood to start off with, then it is obvious that some parts of the body are going to be starved, and hence will not function properly.

Effects of Lack of Oxygen

The Brain

The most important result of lack of oxygen is the effect it has on the brain. Loss of judgement occurs without one being aware of it. In some ways the lack of oxygen is similar to the effects of alcohol. (A.P. 1275, Vol.1, Section VIII, Chapter 1, para. 126).

.../Between

Between 10,000 and 18,000 ft. lack of oxygen makes itself felt by a steady increase in Errors of performance. Comparatively simple mistakes can be made at these altitudes without any knowledge that one is doing wrong. For instance, a Pilot may fly on a reciprocal course or read the wrong instrument, or an air gunner may forget to release the safety catch of his guns.

Physical work and cold at high altitudes will exaggerate these symptons, and if heavy work is being done unconsciousness may eventually occur.

The main point about this is that errors of performance increase without the knowledge of the individual concerned.

Between 18,000 and 25,000 feet, dangerous changes in mental outlook occur. In fact at this height lack of oxygen may make the individual oblivious to all surroundings. This may be followed by sleepiness and finally unconsciousness.

At heights above 25,000 ft. unconsciousness will occur very quickly.

Effects of Cold

Effects of cold upon the body are intensified by lack of oxygen. Frost bite will occur much more quickly if there is also lack of oxygen. This will be partly due to the fact that mental ability decreases with lack of oxygen, so individuals concerned will therefore take less care of themselves.

Cold also causes blood vessels to contract, consequently less oxygen will reach the tissues. In small blood vessels they become so restricted that insufficient blood and therefore oxygen will reach the tissues to nourish them and they will be damaged through oxygen lack.

It is essential, therefore, that sufficient oxygen is supplied under cold conditions, as when cold the body requires more oxygen than normally. (A.M.O. A.247/43 lays down requisite amounts).

Night Vision

At night oxygen should be used from the ground upwards. The cells of the body most sensitive to oxygen Lack are those at the back of the eye which are responsible for seeing at night. So to ensure optimum night vision, use oxygen from the ground at night. (A.O.A. 785/43 amends A.M.O. A.247/43). Especially in fighter a/c. bomber a/c oxygen should be used from 4,000 ft., providing that the endurance of the oxygen supply permits.

N.B. If oxygen is not turned on until 10,000 ft. a red glow in front of the eyes may be noticed. Night vision is therefore temporarily impaired. This will however pass off within one or two minutes when the cells responsible for night vision receive their full oxygen supply.

Fatigue

Lack of oxygen will increase fatigue. So in the event of the crew carrying out any physical work it may be beneficial to turn on the oxygen below 10,000 ft. in daylight.

Air Sickness

Lack of oxygen at altitude increases liability to air sickness.

.../Acclimatisation

Acclimatisation

Why should it be necessary to take oxygen in the region of 10,000 ft.? In the Andes and Himalayas natives spend their lives in the region of 15,000 ft. and mountaineers have climbed to greater heights than this without oxygen. The greatest height reached without oxygen on the Everest Expeditions was estimated at 20,000 ft.

This is made possible by a process known as acclimatisation or the changes which slowly take place in the body to allow it to function at altitude. The red cells in the blood which are responsible for carrying oxygen are produced in increasing numbers. Samples of ood fr m altitude acclimatised people have shown as many as twice the number of red cells per unit volume as in a normal person. Inhabitants of high altitudes usually have abnormally developed chests so that more air is taken in at each breath.

To enable acclimatisation to take place several days must be spent at intermediate altitudes. This is clearly impossible in aircraft so oxygen must be supplied.

Some Common Fallacies

Too much oxygen is not detrimental to health. The only effect of increasing the amount supplied beyond that laid down, is to empty the cylinders in the aircraft more quickly, thus reducing the endurance.

Oxygen has no smell, though in some cases a faint rubbery smell may be detected when oxygen is first turned on. This, however, should not persist more than a minute or two,

It is incorrect to say that lack of oxygen can be recognised by panting or shortness of breath. This may, of course, occur if violent physical exercise is being undertaken at the same time.

Recovery from alcoholic excess can not be accelerated by breathing pure oxygen. This has been proved by experiment.

Lecture No.2

Oxygen Equipment as Used in the Service

Oxygen is supplied to the Service in what are known as transport cylinders. That is a large cylinder of special alloy steel which has been solid drawn. (Weight 290 lbs.).

Outside surface alluminised and painted black - a warning notice stencilled on each cylinder (USE NO OIL OR GREASE - THEY CAUSE EXPLOSIONS).

Date stamp on neck of cylinder. For retest every four (4) years return to M.U. labelled "RETURN FOR FOUR YEARLY TEST."

Cylinder filled with clean oxygen at a pressure of 3,600 lbs. per square inch and contain the equivalent of 16,000 litres at N.T.P.

White line 3" long painted on the cylinder in line with the valve outlet to facilitate location when on multi-cylinder trolleys.

.../Night

Night identification tag. O for oxygen; N for nitrogen; A for air.

For several reasons it can be seen that these cylinders are not suitable for use in aircraft, in any case the pressure is far too high for immediate supply to the crew.

How then is the oxygen carried in the aircraft? and how is the pressure reduced sufficiently for safe use by the crew?

Aircraft Cylinders

Firstly, it is stored in the aircraft in reservoirs until it is required. These reservoirs are in the form of small cylinders of blown steel. This ensures that these are no seams or weak spots in the cylinder which would be liable to give way under high pressure.

The cylinders contain approximately 750 litres of oxygen compressed to 1,800 lbs. per square inch and are fitted in the aircraft so that they may be removed for charging or are permanently fitted in the aircraft so that they may be charged in-situ.

Where cylinders have to be removed for charging they are fitted with valves operated by a hand wheel which may be turned off before removal from the aircraft.

In the case of permanently installed cylinders, they are fitted with three or five way connecting pieces to enable all cylinders to be inter-connected and charged from one fixed point in the aircraft.

The cylindrical portion of the cylinder is wire wound to reduce the chance of the cylinder fragmenting on being hit by a shell splinter, and on the neck of the cylinder is a date stamp similar to that on the transport cylinder.

Charging

How is re-charging of the cylinder carried out?

First, in the case of charging bottles aircraft individually by removal from the aircraft. It can be seen that it would be quite easy just to connect the aircraft cylinder to the transport cylinder and allow oxygen to flow from one to the other.

Apart from this being an extremely tedious business, especially if there are a considerable number of cylinders to be charged. It is extremely dangerous as the pressure in the transport cylinder, when fully charged, is 3,600 lbs. per squareinch and that required in the aircraft cylinder is only 1,800 lbs. per square inch.

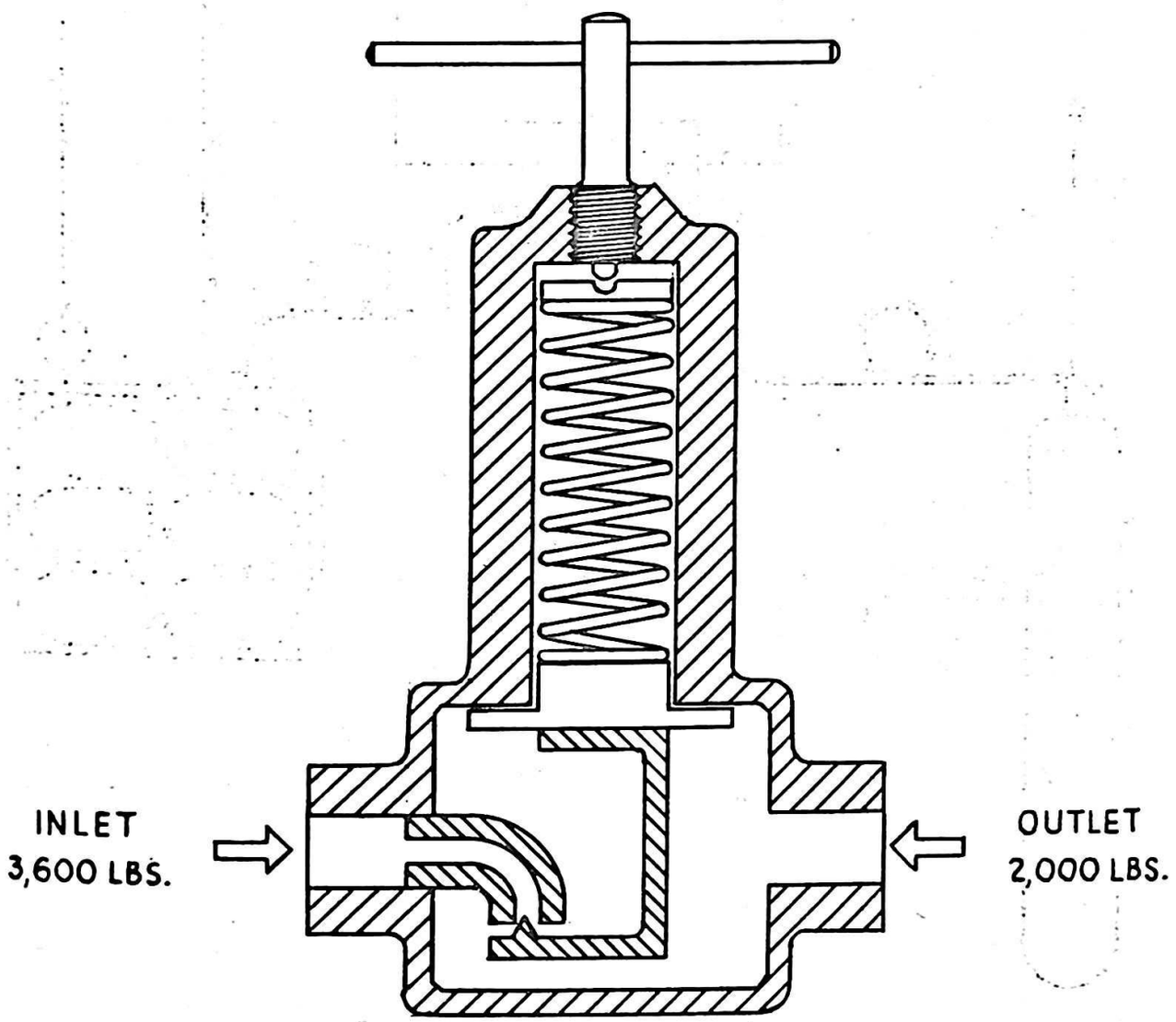
Here, then are two factors which are essential in the charging apparatus:

(a) Some method of re-charging several cylinders at once.

(b) A reducing valve to ensure that the pressure in aircraft cylinders does not exceed 1,800 lb. (up to 2,000 now permissible). (Fig.1).

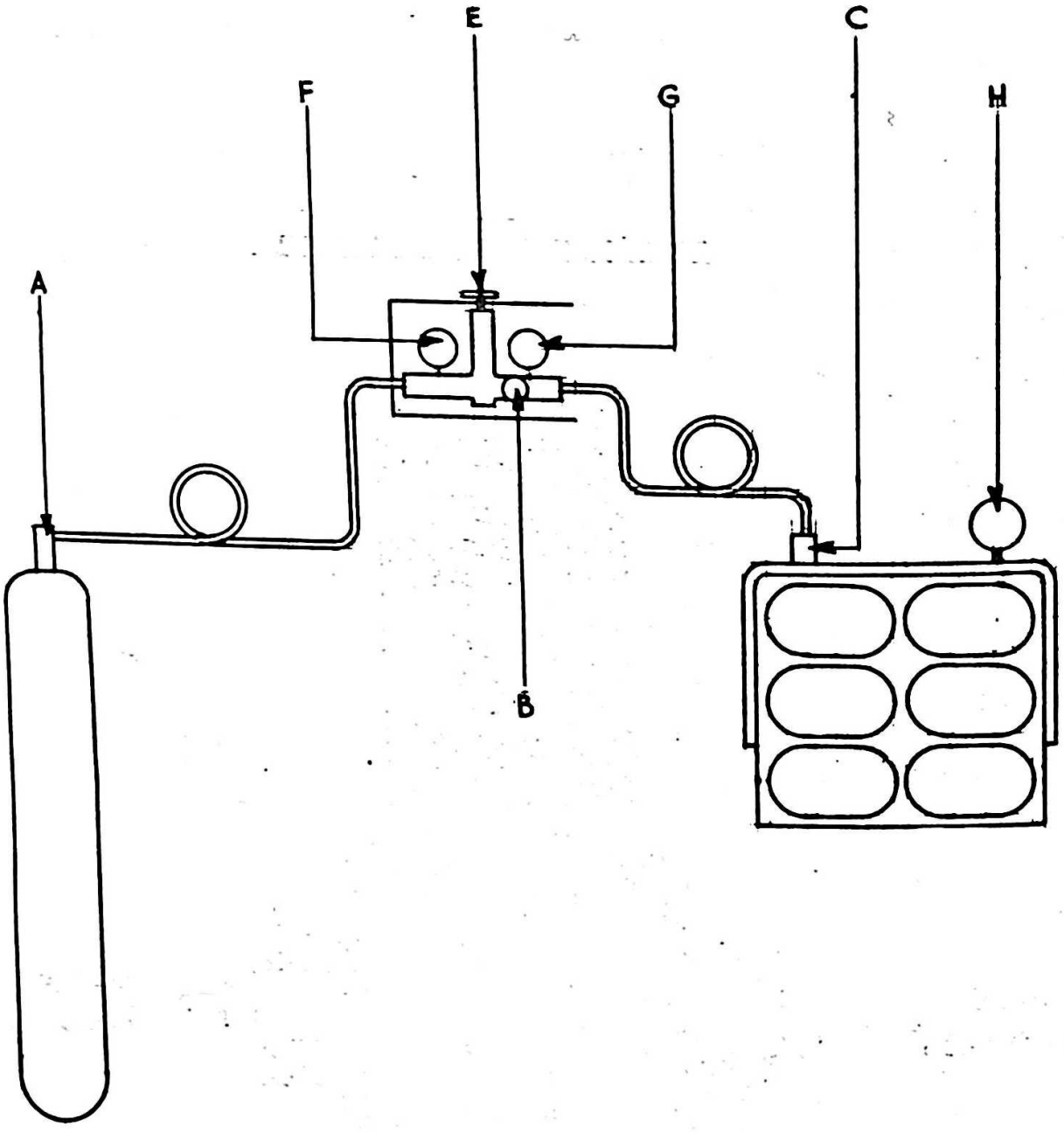
The Charging Rack

(a) is easily overcome by having some form of output for the cylinders and interconnecting them by means of a network of pipelines. This is accomplished in the "Charging rack".



REDUCING VALVE

Fig. I



A. STOP VALVE ON TRANSPORT CYLINDER
B. STOP VALVE ON REGULATOR
C. STOP VALVE ON RACK
E. ADJUSTMENT FOR REDUCING VALVE
F. HIGH PRESSURE GAUGE
G. REDUCED PRESSURE GAUGE
H. CYLINDER PRESSURE

CYLINDER CHARGING

Fig. 2

This rack incorporates mounting for twelve cylinders, which may be fitted by means of quick release connections. (Blanking pieces also incorporated). Stop valve and pressure gauge are also incorporated to enable the rack to be isolated from the rest of the system, and the pressure in the cylinders read off. The purpose of this will be seen later.

High Pressure Regulator

This consists of a reducing valve, a gauge showing transport cylinder pressure and, reduced pressure. A safety valve is also incorporated to blow off at 2,300 lbs. per square inch in the event of failure of the reducing valve.

Use of charging Apparatus (Fig.2)

Connect transport cylinder to High Pressure Regulator and Regulator to charging Rack by special High pressure pipelines.

(1) Close valve on charging rack.
Open valve on Regulator.
Open transport cylinder valve fully.

(2) Check pressure in transport cylinder by means of gauge (F).
Check reduced pressure by means of gauge (G).

(3) Pressure on gauge (G) should be 2,000 lbs. irrespective of gauge F. If incorrect adjust by means of valve E.

N.B. Special three way connections are supplied to enable three transport cylinders to be connected up together.

Charging Cylinders

(1) Inspect cylinders paying particular attention to following points:

(a) Date of last test.

(b) Oil or grease on valve.

(c) Corrosion, under wire binding and round neck of cylinder.

(d) Some oxygen content.

(e) Oxygen does not smell.

(2) Open all valves on charging apparatus and blow through with a blast of oxygen.

(3) Connect cylinders on rack, and open valves. Checking pressure in cylinders when they have equalised. (Gauge H).

(4) Open valve A, check cylinder pressure on gauge F.

(5) Open valve C. aircraft cylinder pressure will be then on gauge (G).

(6) Open valve (B) pressure shown on gauge G will build up to 2,000 lbs. per square inch. When this pressure is reached close valve C. The cylinders at this stage will be quite warm and pressure shown on gauge H will be the same as that shown on G.

(7) Leave the cylinders to cool, and the cool pressure shown on gauge H will drop. If it drops below 1,800 lbs. per square inch some topping up will be necessary.

(8) After removal from the rack, check the cylinder for leaks, preferably by means of leak tester. If leak is excessive, reject cylinders.

(9) Receiving cylinders to be stored in racks pending requirement.

Charging in Situ

Same apparatus as for individual charging with the exception of the rack. The transport cylinders being mounted on a trolley complete with the regulator and a flexible high pressure pipeline for connection on the aircraft supply point.

N.B. Flexible line must not be allowed to trail along the ground, support on barrels or blocks of wood.

The aircraft cylinders are already connected up in the aircraft and must be carefully inspected before commencing charging. Starting from the charging point inspect all soldered joints for security and connections unions for signs of grease or oil.

Inspect cylinders for security and corrosion.

Method of Charging

(1) Connect flexible charging line to aircraft charging point (usually a line valve with a blanking cap).

(2) Ensure that line valve (I) to aircraft regulator is closed and open charging valve (C). Check pressure in cylinder on gauge (G).

(3) Open valve A and check transport cylinder pressure on gauge F.

(4) If satisfactory open valve A.

(5) Rise in pressure in aircraft cylinders will be shown on Gauge G., when 2,000 lbs. per square inch close valves C and B. Allow cylinders to cool and re-check.

(6) If necessary top up.

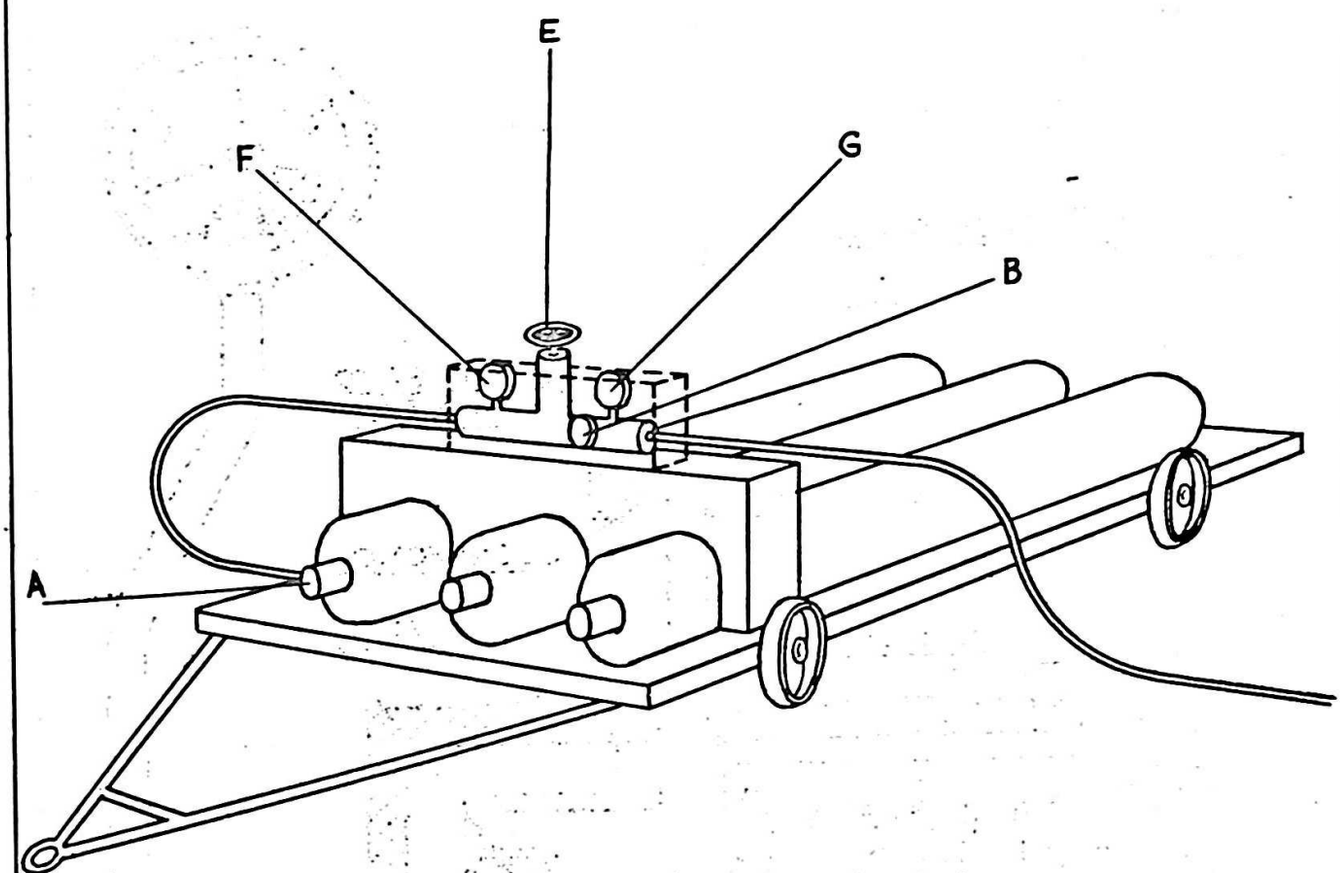
Pressure Regulation

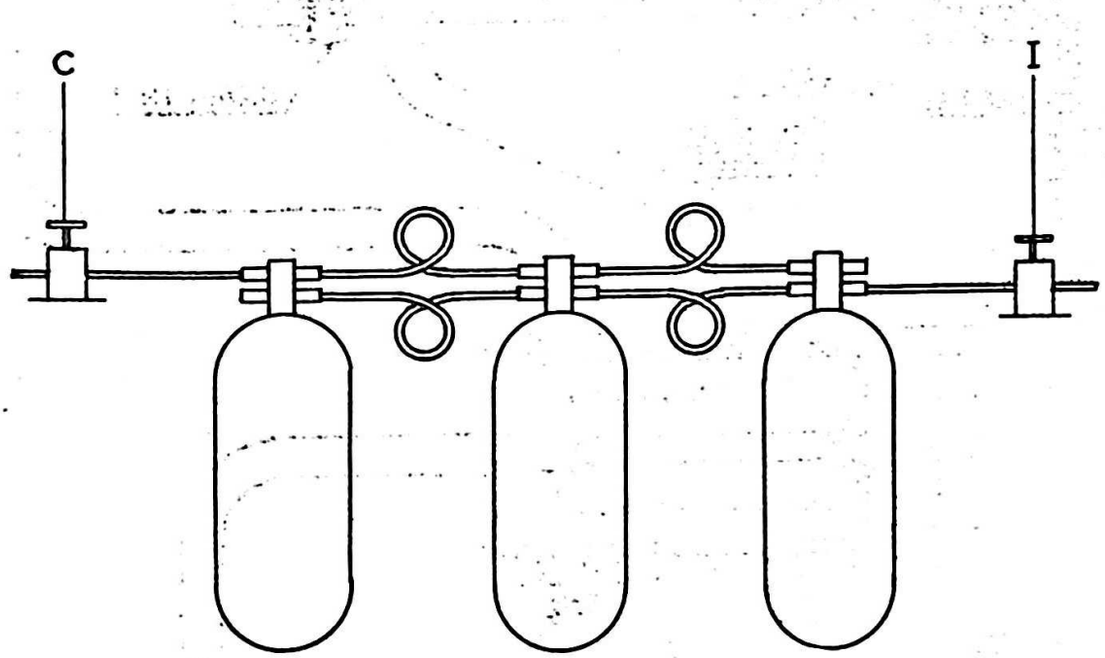
Having eventually got the oxygen stored in the aircraft it is fairly obvious that even now it is impossible to supply it directly to the crew. Normal atmospheric pressure is 14.7 lbs. per square inch and the pressure of the oxygen in the cylinders is 1,800 lbs. per square inch, which is, of course, far too high. So it has to be somewhat reduced.

If the pressure supplied to the crew were too high, it would cause bubbles to form in the blood instead of being properly absorbed. This would cause "bends".

To reduce the pressure still further then high pressure regulators are installed in the aircraft which are under the direct control of the pilot. Thus enabling him to control the amount of oxygen supplied to the crew. These regulators also provide an indication of the amount of oxygen available.

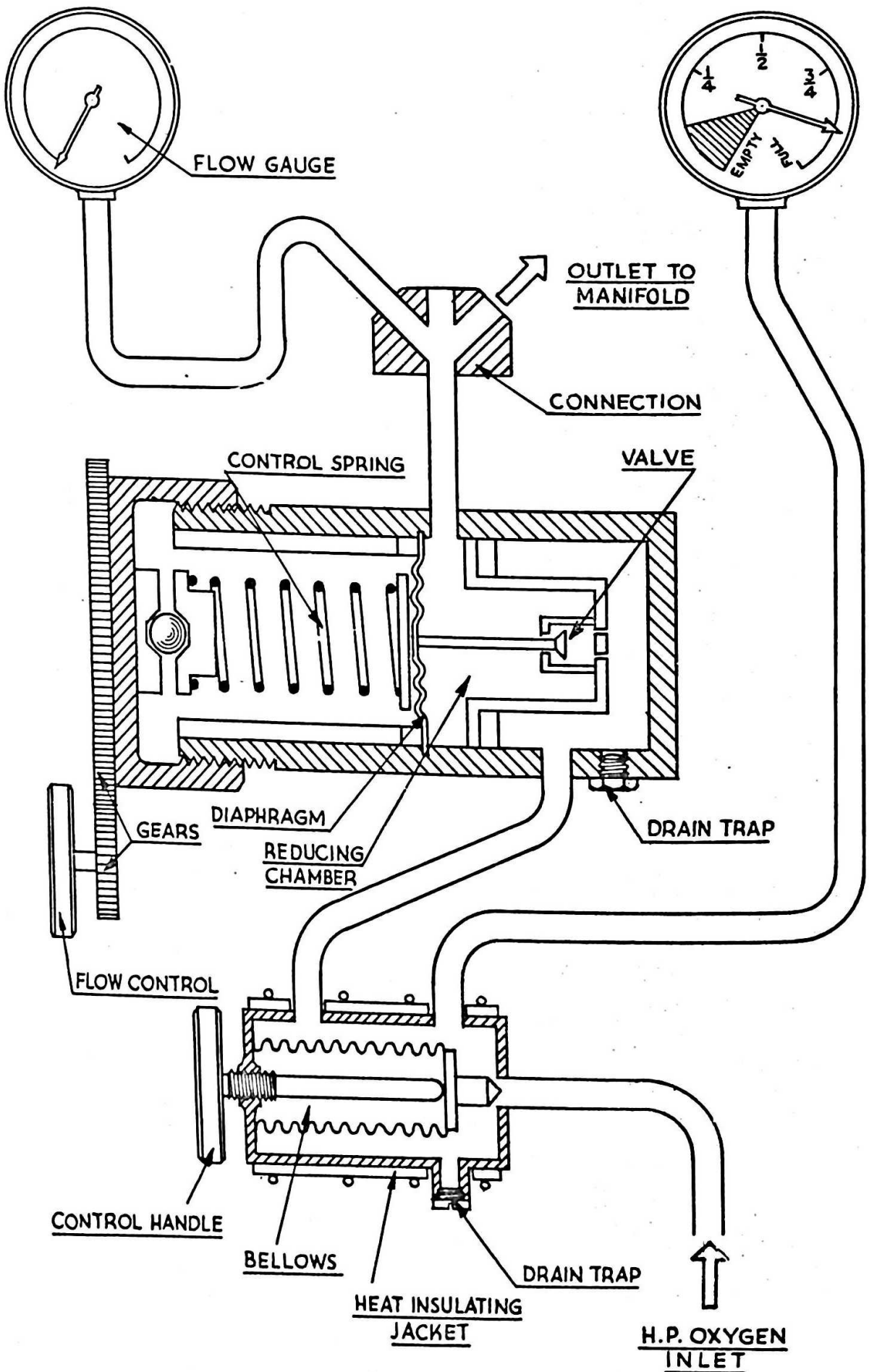
.../Pressure





CHARGING IN SITU

Fig.3



PRESSURE REGULATOR

Fig. 4

Pressure Regulators

There are two types of regulators in use in the service to-day. One for use on bomber aircraft where the crew is more than two, and the other for single seater and two seater aircraft.

Regulator as Used in Bomber Aircraft (Mk. X - A.P.1275, Section VIII, Ch.5)

This regulator is mounted on the aircraft instrument panel so that it is easily visible and available by the pilot or captain of the aircraft.

Oxygen from the aircraft storage cylinders is fed into the high pressure side of it via a glandless on off valve. This valve has a drain trap fitted to it and is wrapped with felt and flannel to provide thermal insulation.

There are two outlets from the valve, the first to a bourden type pressure gauge, which indicates to the pilot the content of the cylinder in the aircraft.

The second connection leads to the reducing valve of the regulator. This valve is adjustable by the pilot to enable him to increase the pressure to which the oxygen is reduced with an increase in altitude.

The Reducing valve of the regulator reduces the pressure of the oxygen to between 20 lbs. per square inch and 60 lbs. per square inch, depending on the setting of the flow control.

The outlet from the regulator is connected to a four-way manifold, the outlets of which contain metering jets. These jets ensure that each member of the crew gets a fully supply of oxygen. If there are more than four in the crew a second manifold may be taken off one outlet of the first.

Before proceeding with the fighter type of Regulator it will be better to complete the system as used in bombers. So far, then, oxygen is fed from the oxygen supply to the regulator where the pressure is reduced by a valve depending on the altitude or necessity as decided by the Captain, from there it is fed to a four way manifold containing metering jets. From where the oxygen is fed to the remainder of the crew.

Before, however, the oxygen reaches the crew it is passed through an oxygen economiser which as its name implies is a device for saving oxygen. It has already been seen that the amount of oxygen supplied to the crew is limited by the regulator. Why then is an economiser necessary?

It can, however, be seen that in the case of the apparatus shown, oxygen is flowing through the manifold in a continuous flow, but the individuals in the crew are only inhaling periodically. Consequently, during the period of exhalation, oxygen is being wasted. The period of exhalation being slightly shorter than that of inhalation, approximately 30% of the oxygen is serving no useful purpose. The oxygen economiser has, therefore, been evolved and is a device whereby the oxygen supply to any member of the crew is automatically cut off as he exhales and recommendes as he inhales.

The operation of this device will be seen later, what we are concerned with at the moment is its effect on the rest of the apparatus.

.../To start

To start with it can be seen that the amount of oxygen which has to be passed to the crew can be reduced by an amount proportional to the saving in oxygen. This is done by recalibrating the supply dials of regulators for use with economisers. Thus on a regulator for use with economisers the 40,000 ft. mark is approximately opposite the 30,000 ft. mark on a normal regulator. In addition manifolds with slightly smaller metering jets are used.

From the manifold the oxygen can be supplied to the various crew positions. Now another snag crops up. Supposing, as in the case of the Navigator or bomber, the crew have two positions, or for some other reason they have to leave their position, then it must be possible to shut off the oxygen supply at that point, otherwise there will be a certain amount of wastage. To overcome this automatic"shut off" valves are fitted in all positions with the exception of the pilot; it is not considered necessary in the case of the pilot, as his position is supposed to be occupied continuously.

It is now possible to complete the installation. Firstly, the pilot's or captain's position. No "shut off" valve so the oxygen supply flows straight to the economiser.

The Oxygen Economiser (Fig.6)

Flexible bellows, closed under the tension of a spring controlled plate. Oxygen from the manifold flows into this bag and forces it open. When it is fully open pressure in the bag forces a valve in the outlet open permitting the oxygen to flow out past the valve.

If this valve is so constructed that the outlet is connected to a breathing mask, and the inhalation of the individual wearing the mask is sufficient to decrease the pressure above the valve to such an extent, that the oxygen pressure in the bag will force the valve open. The oxygen will flow as the individual breathes in, as he breathes out, however, the valve will be forced down preventing oxygen from flowing and allowing the pressure in the bag to build up again ready for the next inhalation. Thus it can be seen that oxygen will only flow when the individual is inhaling. Flow being shut off as he exhales.

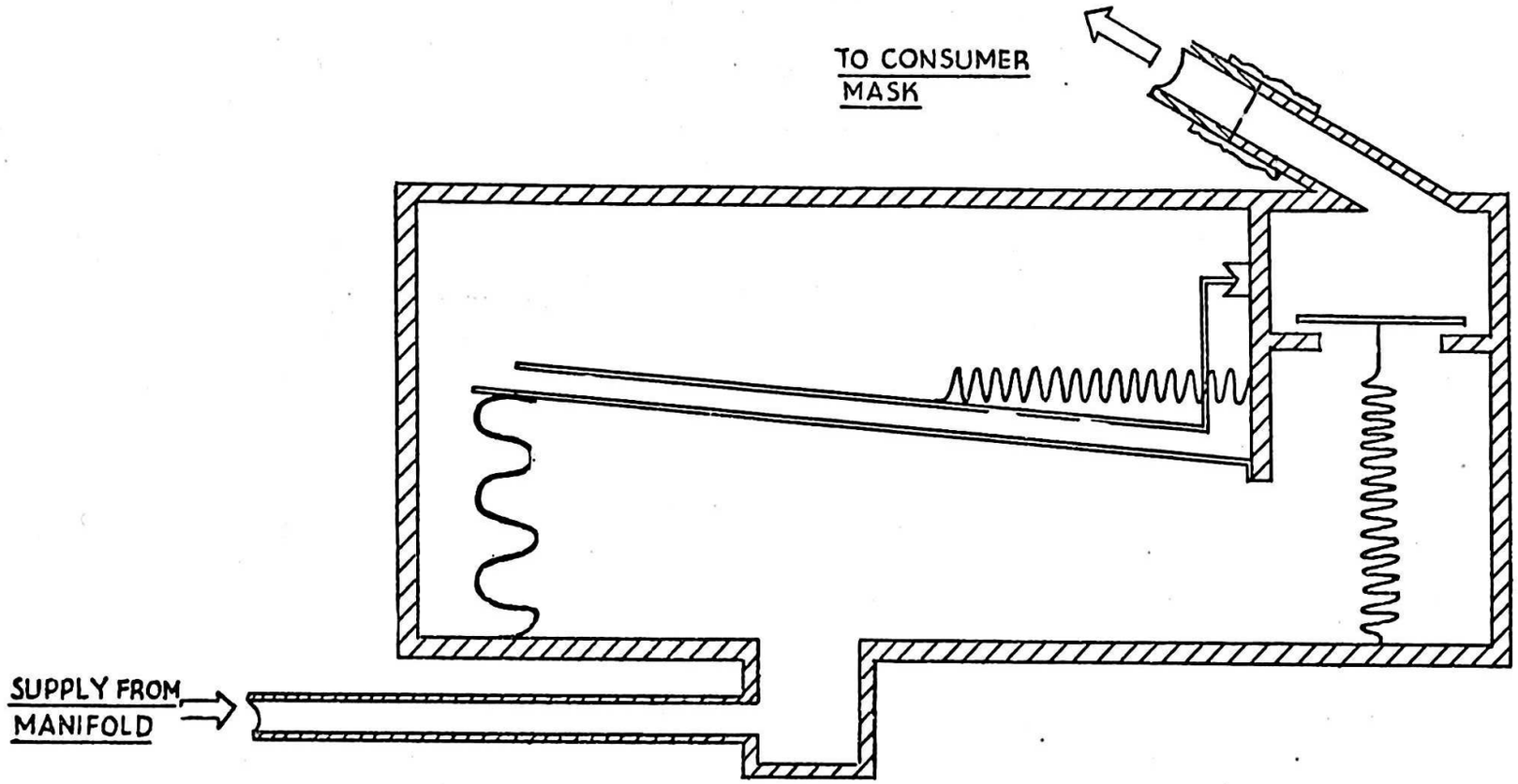
The outlet tube from the economiser is connected by means of a flexible rubber tube to a bayonet or quick release socket into which the breathing mask is plugged.

If the particular oxygen economiser was not in use and the oxygen supply was switched on, it can be seen that as the pressure in the bag builds up the valve will open and oxygen will flow out, decreasing the pressure. The valve again closes and the pressure begins to build up once more. This will go on continuously until either the oxygen supply is exhausted or turned off. Oxygen will, of course, be wasted.

To prevent this possibility a "shut-off" valve is situated in the line between the manifold and the economiser. This valve incorporates a stowage for the bayonet socket and is so constructed that stowing of the bayonet socket automatically shuts off the oxygen supply. Between the shut off valve and economiser a flowmeter is installed which indicates whether or not oxygen is flowing.

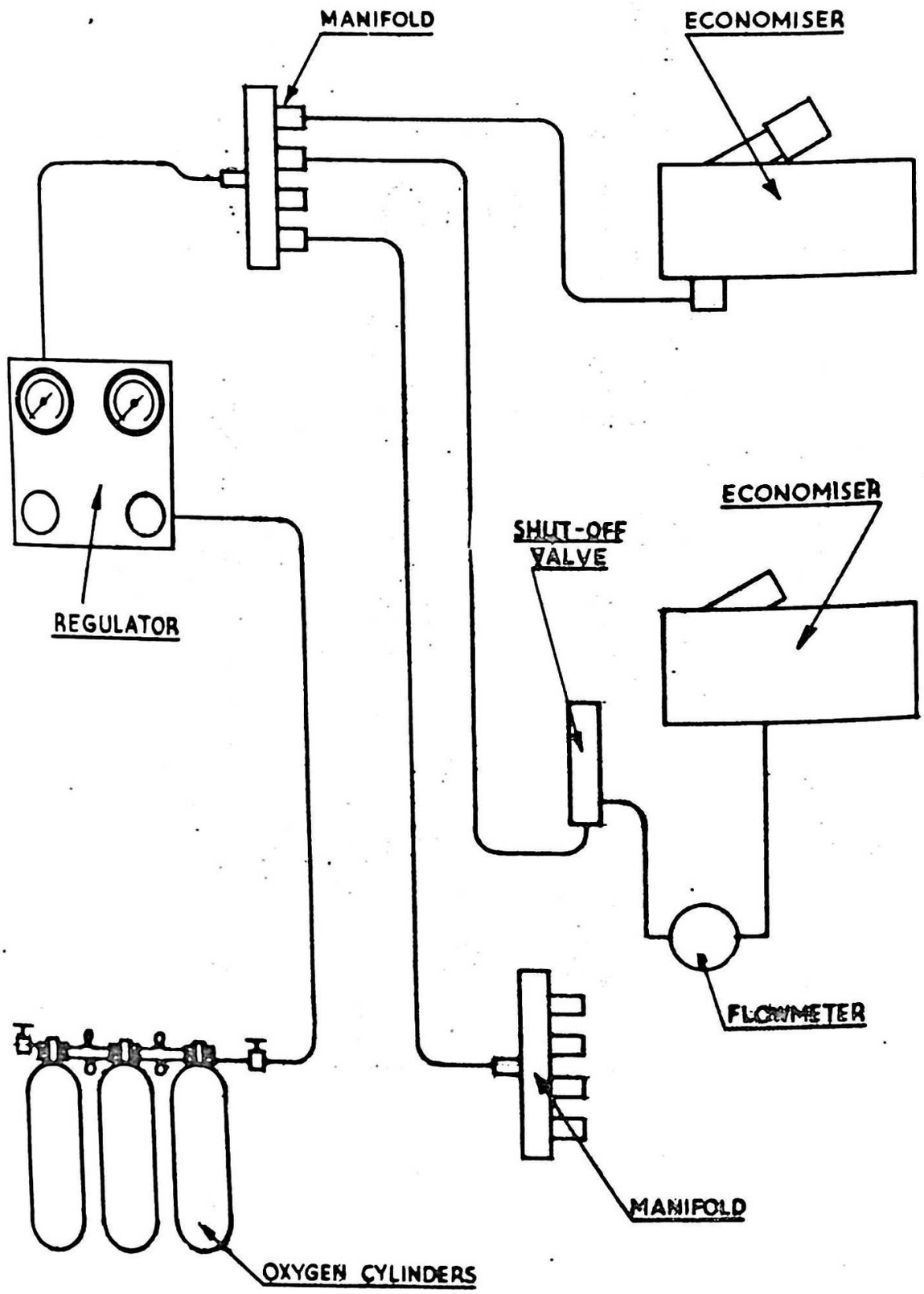
If more positions are required than is possible to supply with one manifold, a second may be tapped off from the first.

.../Regulator



OXYGEN ECONOMISER

Fig. 6



OXYGEN SYSTEM : AIRCRAFT

Fig. 5

Regulator as Used in Two Seater or Single Seater Aircraft

Oxygen flow cannot be fully regulated. It has only two positions, that is two rates of flow. The first giving sufficient oxygen for flying to 25,000 ft. the second for flights up to 40,000 ft.

Oxygen supply is fed in through a glandless on off control similar to that in the previous regulator and again has two alternate paths. One to a bourdon tube type pressure gauge, calibrated in contents or oxygen supply. The second path is through a reducing valve similar to the previous type, but the tension of the controlling spring in this type is not immediately adjustable.

From this reducing valve, oxygen at reduced pressure passes through a pipeline to a flow indicator, also into the height control valve. With the height control valve in the normal position the oxygen passes straight through this valve to the second position, (i.e., Navigator or gunner) and through the flow indicator to the pilot's position. Metering jets are fitted to reduce the flow of oxygen to these positions.

With the control valve set too high an additional flow is permitted through the control valve, one linking up with the second position through a second metering jet. The other linking up with the pilot's position through the record flow indicator tube, thus increased supply of oxygen is permitted to both positions.

An Emergency flow valve is fitted on some types which may be used if any lack of oxygen supply is suspected. This enables the metering jets to be by-passed, and fuel oxygen supplied from the reducing valve to the pilot's position.

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ELECTRICAL & INSTRUMENT SECTION

HENLOW DIVISION, R.A.F. TECHNICAL COLLEGE

THE LINK TRAINER

Instrument Precis No. 6

Introduction

1. GENERAL. (a) For the purpose of explanation the Trainer may be divided into three sections, namely, Base, Fuselage, and Instructor's Desk.

(b) The complete unit contains the mechanisms, instruments and controls necessary for the simulation of an airplane on instrument flight.

2. BASE. (a) The trainer base contains the vacuum turbine, the wind drift mechanism, the telegon oscillator and the base terminal box, together with the necessary electrical and mechanical linkages connecting the base, fuselage and desk.

(b) The main bearing housing is also considered part of the trainer box.

3. FUSELAGE. (a) The fuselage is mounted on a universal joint which permits bank, pitch and turn movement in excess of manouvres normally required of an airplane during instrument flight.

(b) The universal joint is mounted on a turnable octagon. The revolving OCTAGON is attached to a spindle which is mounted in the main bearing housing, this housing being bolted to an iron cross attached to the Square base of the Trainer. The fuselage, revolving octagon and spindle are free to rotate indefinitely in either direction.

4. INSTRUCTOR'S DESK.

(a) The instructor's desk houses the radio, which reproduces the aural and visual radio signals encountered in actual flight, together with the automatic recorder and controls for the wind drift mechanism.

(b) Duplicate altimeter, airspeed and vertical speed, are also located on the instructor's desk, as well as the azimuth control for the automatic Radio Compass.

5. VACUUM SYSTEM.

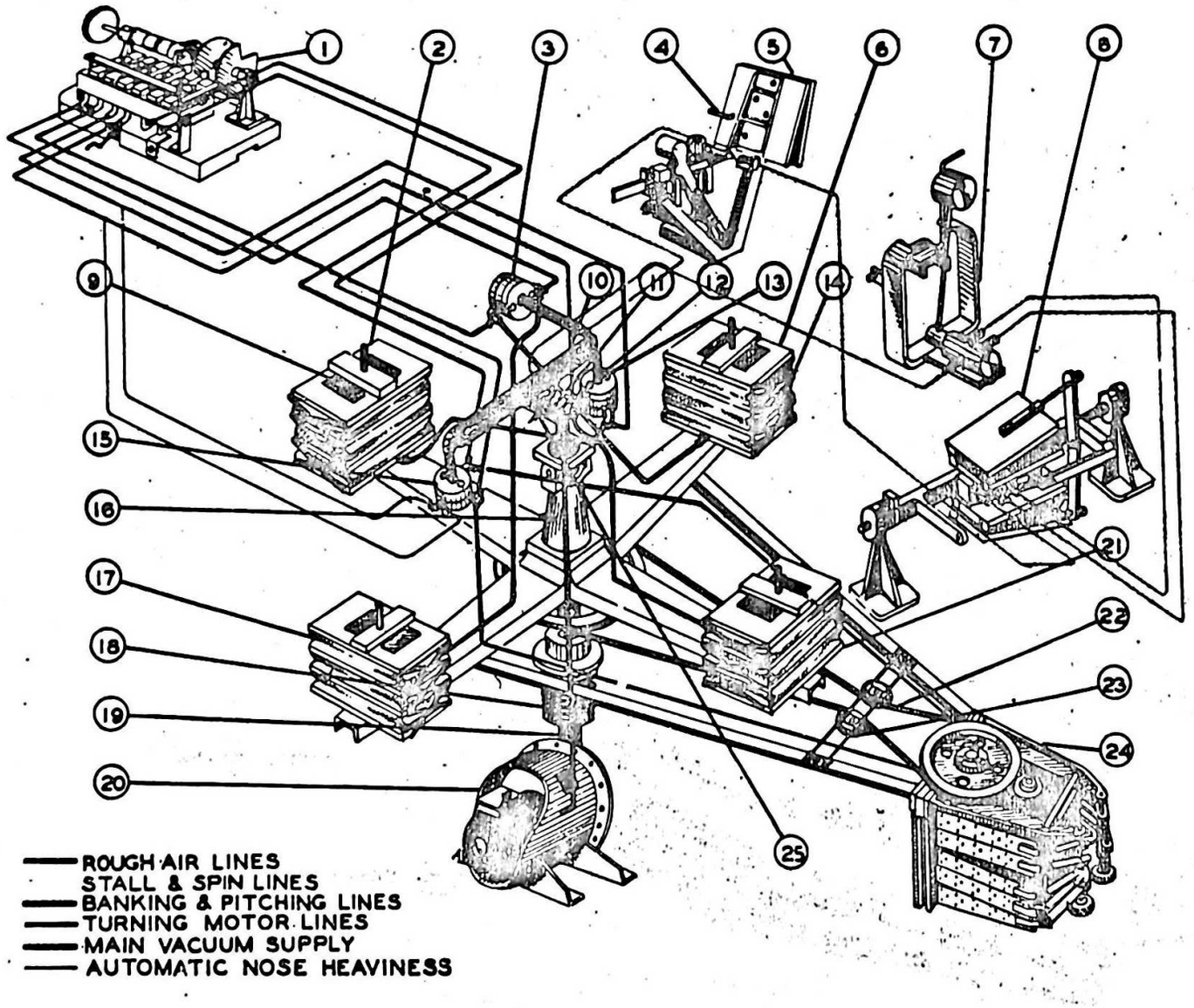
(a) Movement of the Trainer is accomplished by Vacuum operated bellows, controlled by valves which are connected through linkages to the wheel (or stick) and rudder pedals.

(b) The following instruments are also Vacuum operated:-

(1) Tachometer
(2) Air-Speed Indicator
(3) Vertical-Speed Indicator
(4) Altimeter
(5) Directional Gyro
(6) Turn and Bank Indicator

(c) The Trainer Vacuum Supply is obtained from a four-stage (four impellors) centrifugal type blower, having a capacity of approximately 12 cubic feet per minute at $4-\frac{3}{8}$ inches Hg. Power for operation of the turbine is supplied by a $\frac{3}{4}$ H.P. universal type motor. The turbine and motor are contained in one unit which is located in the base of the Trainer.

(d) An Auto Type constant Voltage transformer, mounted conveniently near the trainer, maintains a constant voltage, irrespective of variation in line loading. Through its use, Vacuum pressure in the



1. Rough Air Generator
2. Rear Main Bellows
3. Aileron Valve
4. Air-Speed Vacuum Line
5. Stall Valve Assembly
6. Left Banking Bellows
7. Spin Valve
8. Spin Trip Assembly
9. Bellows Release Flap
10. To Tachometer Regulator Bellows
11. To Air-Speed Regulator Bellows
12. To Climb Valve
13. Elevator Valve
14. Bellows Toggles
15. Rudder Valve
16. Universal Joint
17. Right Banking Bellows
18. Collector Rings
19. Transfer Elbow
20. Vacuum Turbine
21. Front Main Bellows
22. Turning Belt
23. Belt Tightener
24. Turning Motor
25. To Directional Gyro and Turn and Bank Indicator

Fig 1. Air System

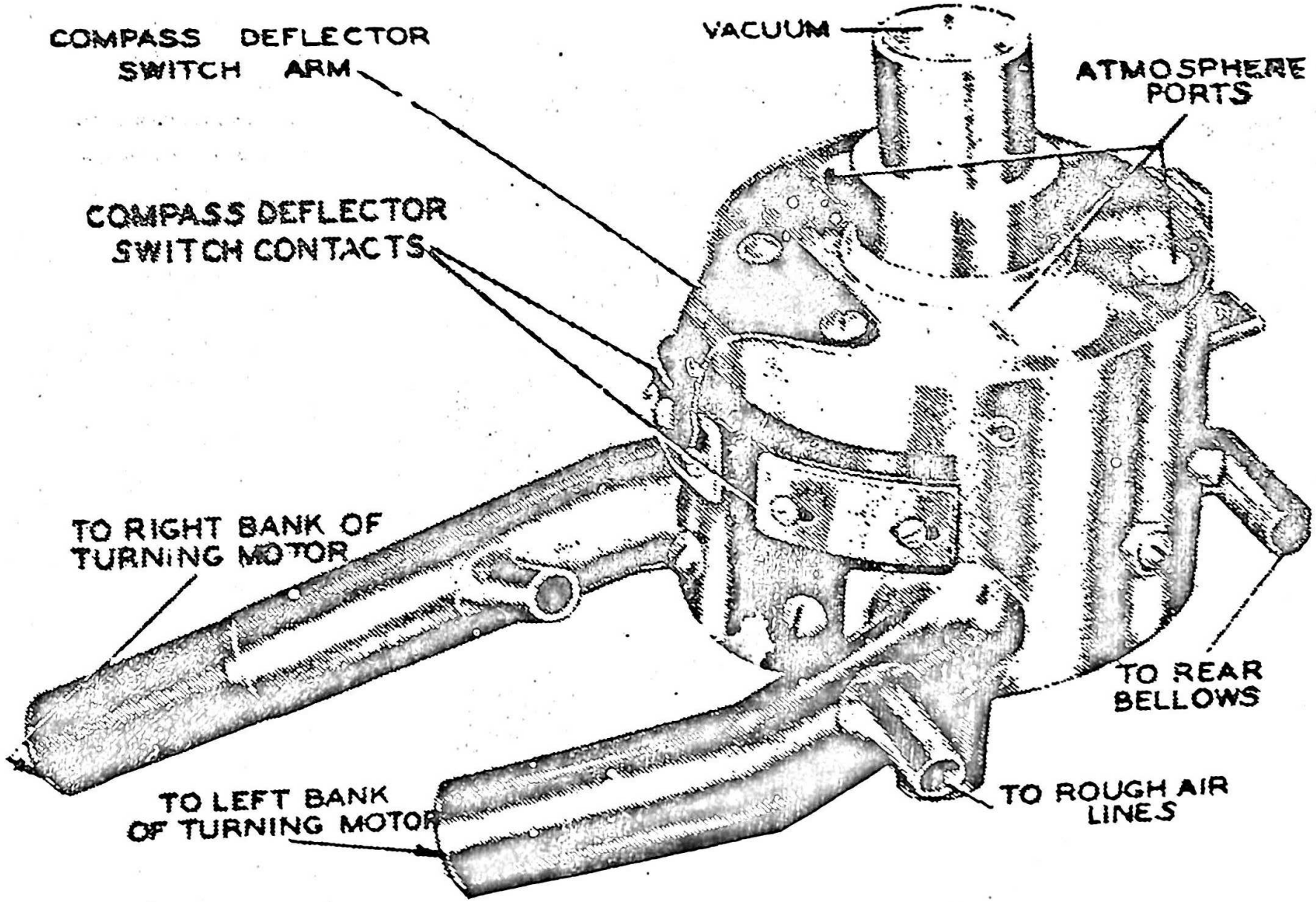


Fig. 2.- Rudder Valve

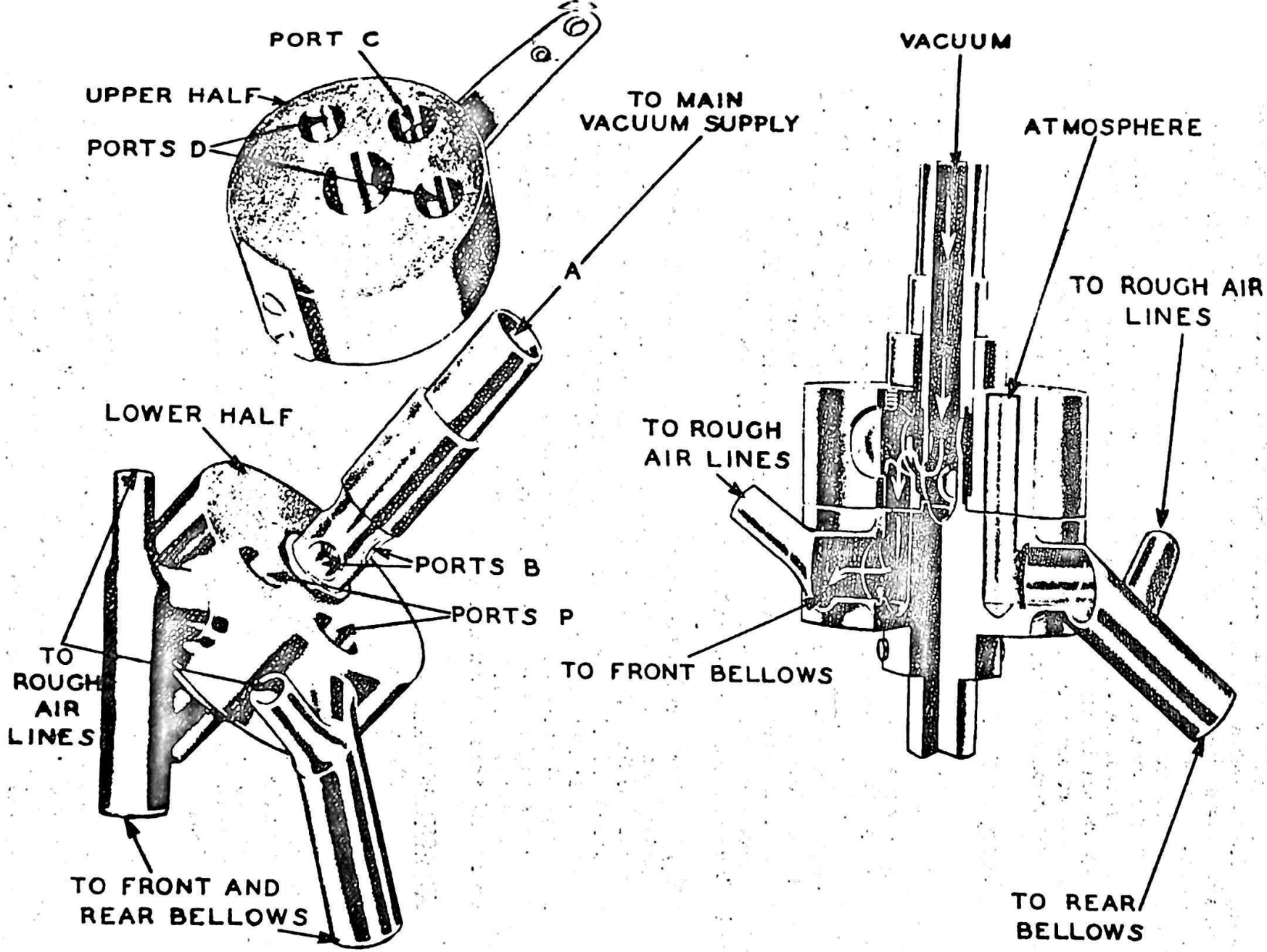


Fig. 3. - Elevator Valve (Cutaway)—Showing Operation

MOTION OF THE TRAINER AROUND THREE AXES

6. BANKING. (a) Banking motion is obtained by two of the four large bellows located under the fuselage in the revolving OCTAGON, one to the right of and the other to the left of the Universal joint. When the vacuum turbine is operating, these two bellows are exerting a downward pull on the fuselage on both sides of the Universal joint. So long as this downward pull is equal on both sides of the fuselage, the Trainer remains level, laterally.

(b) Vacuum is supplied to these two bellows through the two-way aileron valve, which is connected by a compensatory link rod to an arm on the torque shaft, which extends along the centre line of the fuselage a few inches, above the trainer floor. The torque shaft is connected to the interchangeable wheel and stick control, so that movement of the control wheel or stick to the right or left operates this aileron valve, causing more vacuum to be applied to one bellow, while less vacuum is applied to the opposite bellows, thus increasing the downward pull on one side of the fuselage and decreasing the downward pull off the opposite side, causing the trainer to Bank.

7. CLIMBING OR DIVING

(a) Nose-up or nose-down motion of the Trainer is obtained by the other two of the four large bellows, which are located in the revolving octagon, one in front of and the other behind the universal joint. These two bellows are controlled by a two-way elevator valve, similar to the aileron valve, which is connected by a link rod directly to the control column. Consequently, pushing the wheel or stick forward actuates the elevator valve so the vacuum is increased in the front bellows and decreased in the rear bellows, causing the Trainer to Nose-down. When the wheel or stick is pulled back, the reverse of this action takes place and the Trainer noses-up.

7. TURNING. The turning motion of the Trainer about the vertical axis is obtained by the use of a vacuum operated turning motor. The turning motor is reversible and is controlled by a two-way rudder valve similar to the aileron and elevator valves. This rudder valve is connected by linkage to the rudder pedals in such a manner that pushing the right-hand rudder pedal actuates the rudder valve so that increased vacuum is applied to the right side of the turning motor, causing the trainer to turn to the right, Pushing forward on the left-hand rudder pedal causes the reverse of this action and the trainer turns to the left.

9. STRAIGHT AND LEVEL FLIGHT.

The aileron and elevator valves are so constructed that when the control wheel or stick is in a centered position, a small amount of vacuum is being applied equally to the two bellows controlled by each valve. This downward pull, exerted equally by the four main bellows on all four sides of the Universal joint, maintains the Trainer in a level position in relation to the longitudinal and lateral axes. When the rudder valve is centered also, a small amount of vacuum is being applied equally to both sides of the turning motor, thus preventing the trainer from turning.

10. SLIP-STREAM SIMULATORS.

Three slip-stream simulators are used in the Trainer - and they are connected to the Aileron, Elevator, and rudder controls. These units are designed to load the controls to simulate the stiffening effect caused by air passing over the control surfaces of an airplane in flight. The body of the Unit contains vanes, mounted on a large shaft, operating in fluid filled comparments. The fluid flows from one side of each vane to the other through a valve which can be adjusted to furnish the desired resistance to elevator, aileron, or rudder control movement.

.../11.

11. TURNING MOTOR. The turning Motor is vacuum operated and consists, in reality, of two distinct motors, each with one bank of five double bellows, connected to a crankshaft by connecting rods. The crankshaft of both banks of the motor are geared to the same reduction gear unit, terminating on a pulley for a round belt. Each bank is connected by a separate vacuum line to the rudder in such a manner that when right rudder is applied vacuum is caused to operate on the righthand bank causing the trainer to turn to the right, while application of the left rudder causes vacuum to tbe applied to the left bank causing the trainer to turn to the left. Due to the construction of the rudder valve, when vacuum is being applied to one bank of the Motor, atmosphere is being applied to the other, so that when one bank is operating the other is idling. The bellows are double acting and are operated by sliding hardwood valves. The connecting rods are made of hardwood impregnated with beeswax.

12. ROUGH AIR GENERATOR.

The rough air generator is located in the rear of the fuselage and is operated by a small constant speed electric motor located under the pilot's seat. Current to this motor is controlled by the trainer main switch and it is, therefore, always in operation when the trainer is running. The p rpose of the rough air generator is to simulate in the trainer the effect of air currents on an airplane. This is accomplished by means of six cam operated flap valve on the rough air generator, which are connected into the vacuum lines leading to the banking and pitching bellows, and to the two banks of the turning motor. The rough air generator is turned on or off by means of a crank located under the rear of the fuselage. The mechanical arrangement of the cams and the rough air flap valves is such that, a momentary leak of atmosphere is admitted alternately to each of the bellows and, in the case of the turning motor bellows, a constant leak of atmosphere is shut off momentarily to alternate banks of the turning motor.

13. MAIN VALVES. The three main valves (Rudder, Aileron, Elevator) are all somewhat similar in design and operation in so far as their primary functions of causing turning, banking and pitching (climbing and diving) movements of the trainer is concerned. Certain Mechanical differences have been incorporated in the rudder valve and aileron valve in order to make possible their secondary function of causing "Nose heaviness during turn" and "automatic bank with turn" respectively.

14. NOSE HEAVINESS DURING TURN.

Nearly all airplanes have a tendency to automatically nose down during a turn without forward movement of the elevator control. This tendency is reproduced mechanically in the trainer by means of special ports in the rudder valve connected through the rough air line to the front and rear (dive and climb) bellows.

The proper proportion of nose heaviness during a turn is arrived at in the design of the valve and the size and location of the parts and no provision has been made for further adjustments. Due to the positioning of the ports in the valve, the extent of nose heaviness is in direct proportion to the rapidity of the turn or the distance the rudder pedal is pushed forward.

15. AUTOMATIC BANK WITH TURN.

Nearly all airplanes have a tendency to bank automatically, without the aid of the ailerons - whenever rudder is applied. This tendency is reproduced mechanically in the trainer by interconnecting the rudder pedals by linkage with a specially constructed type aileron valve.

By comparing the automatic bank with turn type aileron valve with the main elevator valve it can be seen that, in order to reproduce the automatic bank with turn, a centre leaf has been placed between the upper and lower halves of the valve.

.../On trainers,

On trainers, link serial No.4395 to 5550, inclusive, the outer leaf of the aileron valve is connected by linkage to the bell crank and then, by means of the aileron valve compensator rod, to the spin trip walking beam. The top of the spin trip walking beam is connected by a link rod to the rudder bar which is actuated by movement of the rudder pedals. It can be seen, therefore, that movement of either the right or left rudder pedal rotates the centre leaf of the aileron valve, causing the trainer to bank when turning.

On trainers beginning with link serial No.5551, the centre leaf is connected by linkage to an improved bell crank which is connected by a link rod directly to the rudder bar. This newer bell crank assembly increases the effectiveness of the automatic bank with turn feature, causing the operation and effect of the controls to more closely simulate the automatic bank with turn characteristic of an airplane. It also eliminates the necessity of applying full opposite aileron control to recover from a bank and, when the proper angle of bank has been attained during a turn, the application of only a very little opposite aileron control is necessary to maintain it.

16. AUTOMATIC TURN WITH BANK. (See Fig.6)

This tendency is reproduced in the trainer by means of the bank turner assembly. This assembly is located on fuselage floor parallel to the lateral axis, with a link rod (A) mounted to the iron cross on the base of the octagon at the right of the longitudinal axis. Due to its location, the movement of the trainer about its lateral axis (climbing or diving) will have no effect upon this unit. However, when the trainer is banked the distance is varied between the fuselage floor and the octagon. This in effect moves the horizontal arm (B) up and down which rotates the shaft (C) moving the bottom of the bell crank (D); Since the top of the walking beam (E) is stationary, due to the centered position of the rudder pedals, the walking beam pivots at point (E) imparting motion to the compensator link rod (F) which is connected to the rudder valve. This causes the upper part of the rudder valve to be rotated, which in turn causes the trainer to turn in the direction in which it is banked even though the rudder pedals are in a centered position. As movement of the linkage connecting the bank turner assembly to the rudder valve is proportionate to the extent to which the trainer is banked, the tendency of the trainer to turn when banking is in direct proportion to the extent to which the wheel or stick is moved to the right or left.

17. STALLING - STALL VALVE ASSEMBLY.

(a) When the speed of an airplane drops below a certain minimum the airplane "stalls" and sometime starts to "spin". This characteristic is built into the trainer and is a function of the stall valve assembly.

(b) The bellows of this assembly is connected by tubing to the line leading from the air-speed regulating bellows to the air-speed indicator. Thus the same amount of vacuum is applied to the stall valve bellows as to the air speed indicator.

(c) At normal air speed this vacuum pressure is sufficient to keep the stall valve bellows collapsed and overcomes the tension of the spring on the stall bellows. In this position the inverted pendulum rests against the adjustable stop screw. At normal air speed the pendulum is being held, against the stop screw and atmosphere is continually entering the atmosphere vent in the three way, jet assembly between the line from the main vacuum supply and the line to the spin trip bellows. Due to a restriction built into the vacuum side of this connection, the atmosphere entering the atmosphere vent is sufficient to reduce the vacuum to the spin trip bellows, line so that the spinstrip bellows remains open.

(d) As the air speed is decreased the vacuum in the stall bellows is correspondingly reduced. When it is reduced to a certain point, the spring tension is able to overcome the vacuum and pulls the stall bellows open. As the bellows open, the pendulum is pulled back against

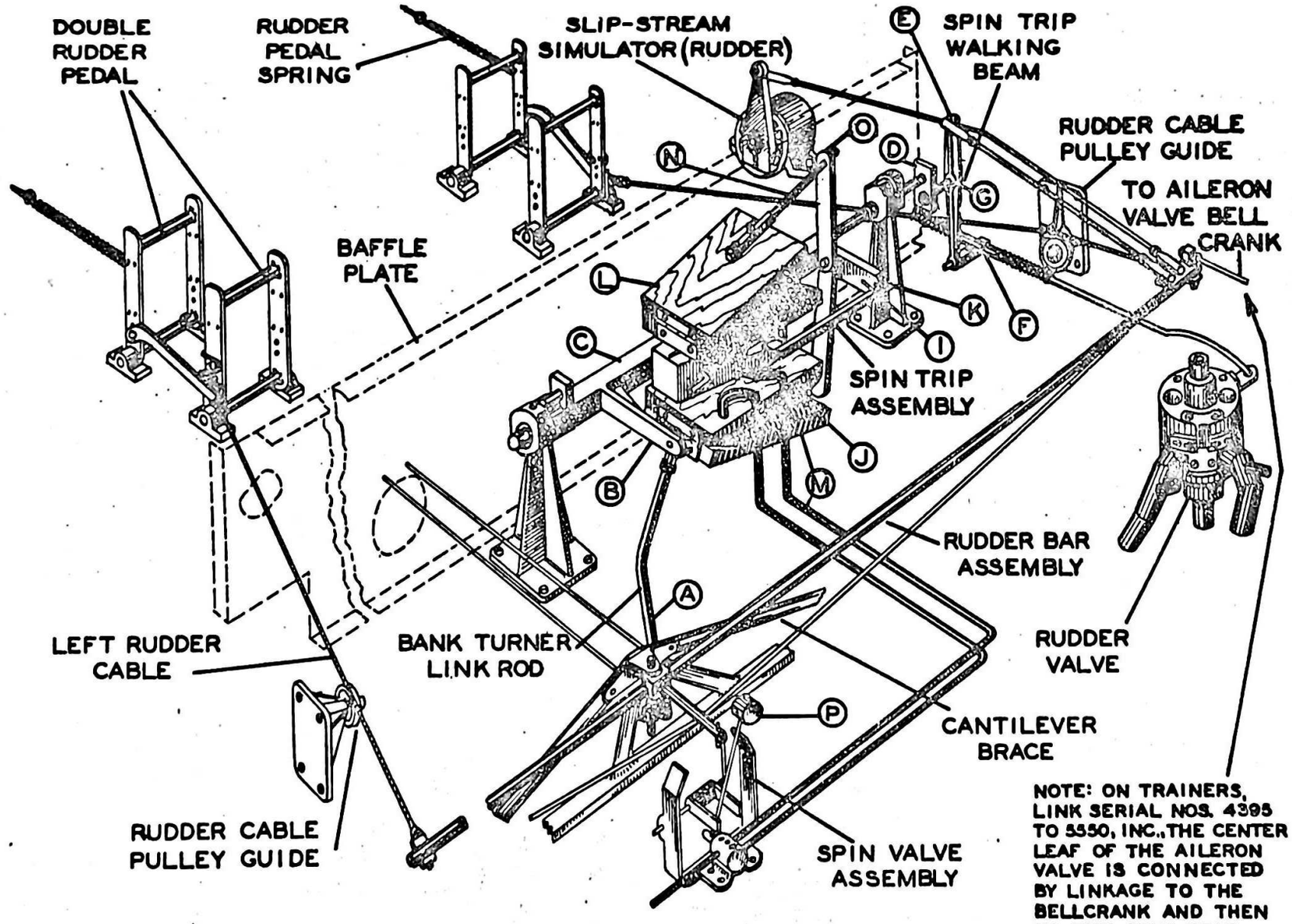


Fig 6 **Directional Control (Schematic)**

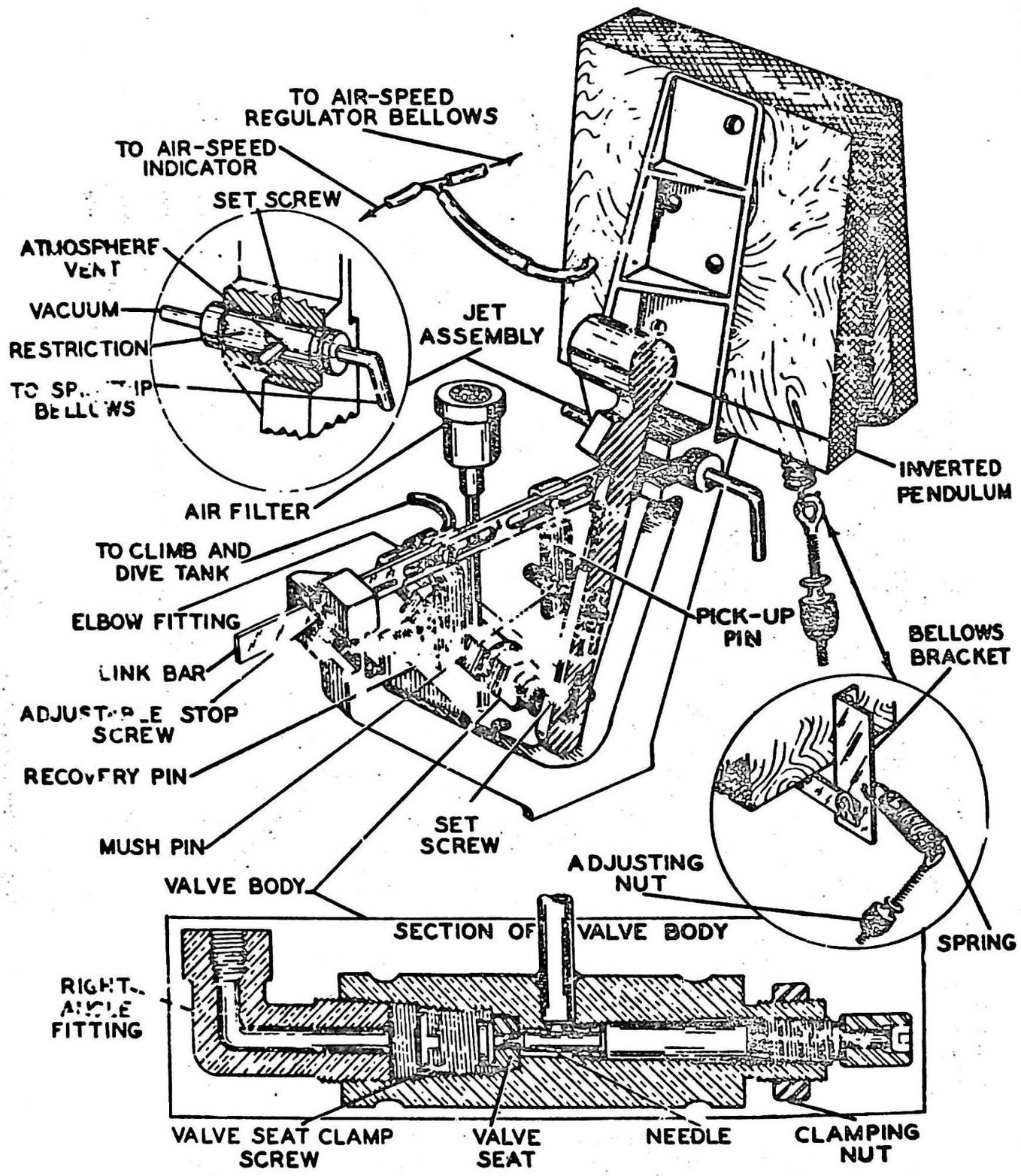


Fig. 5. **Stall Valve**

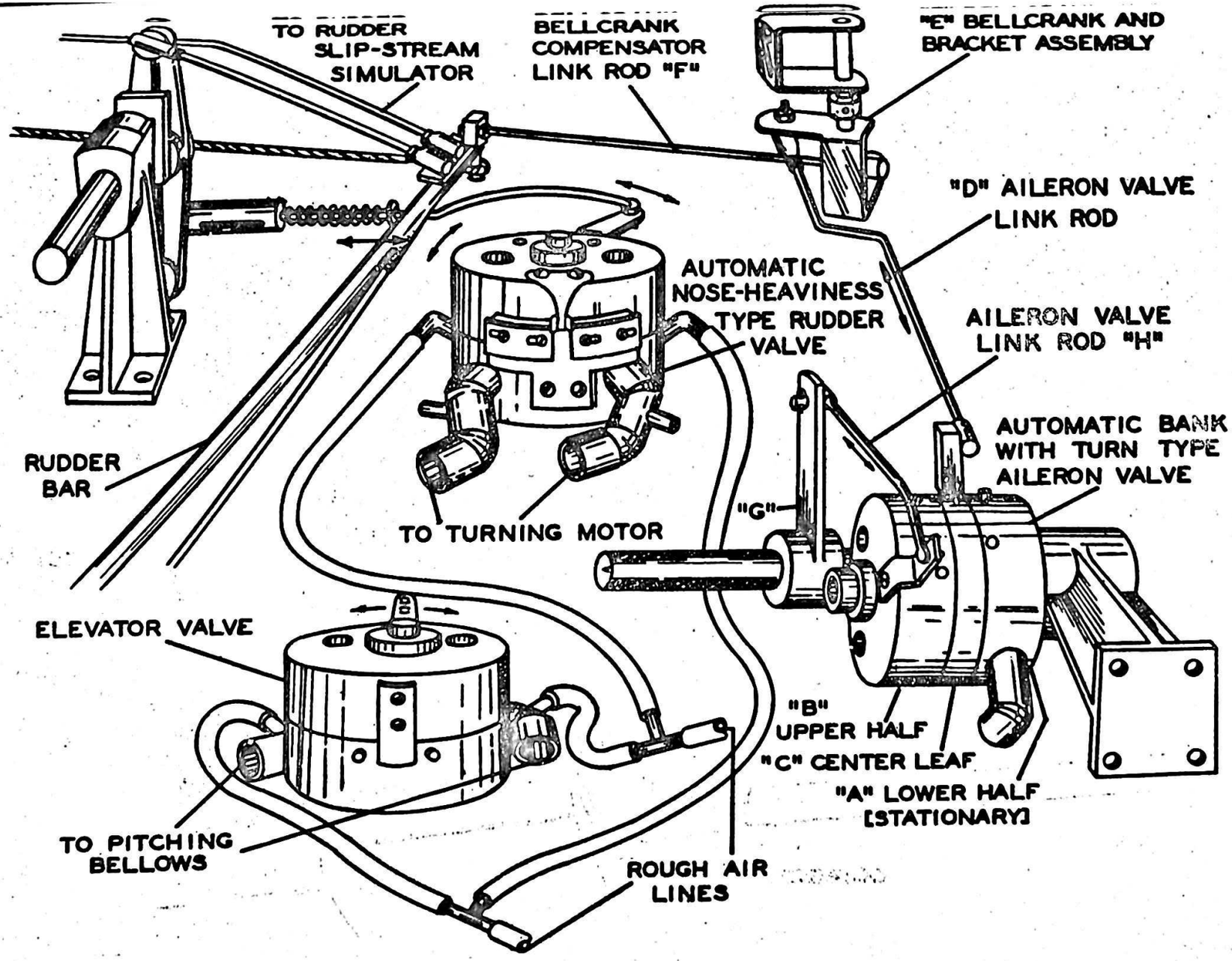


Fig 4 ***Main Valves with Connecting Linkages***

F. 46

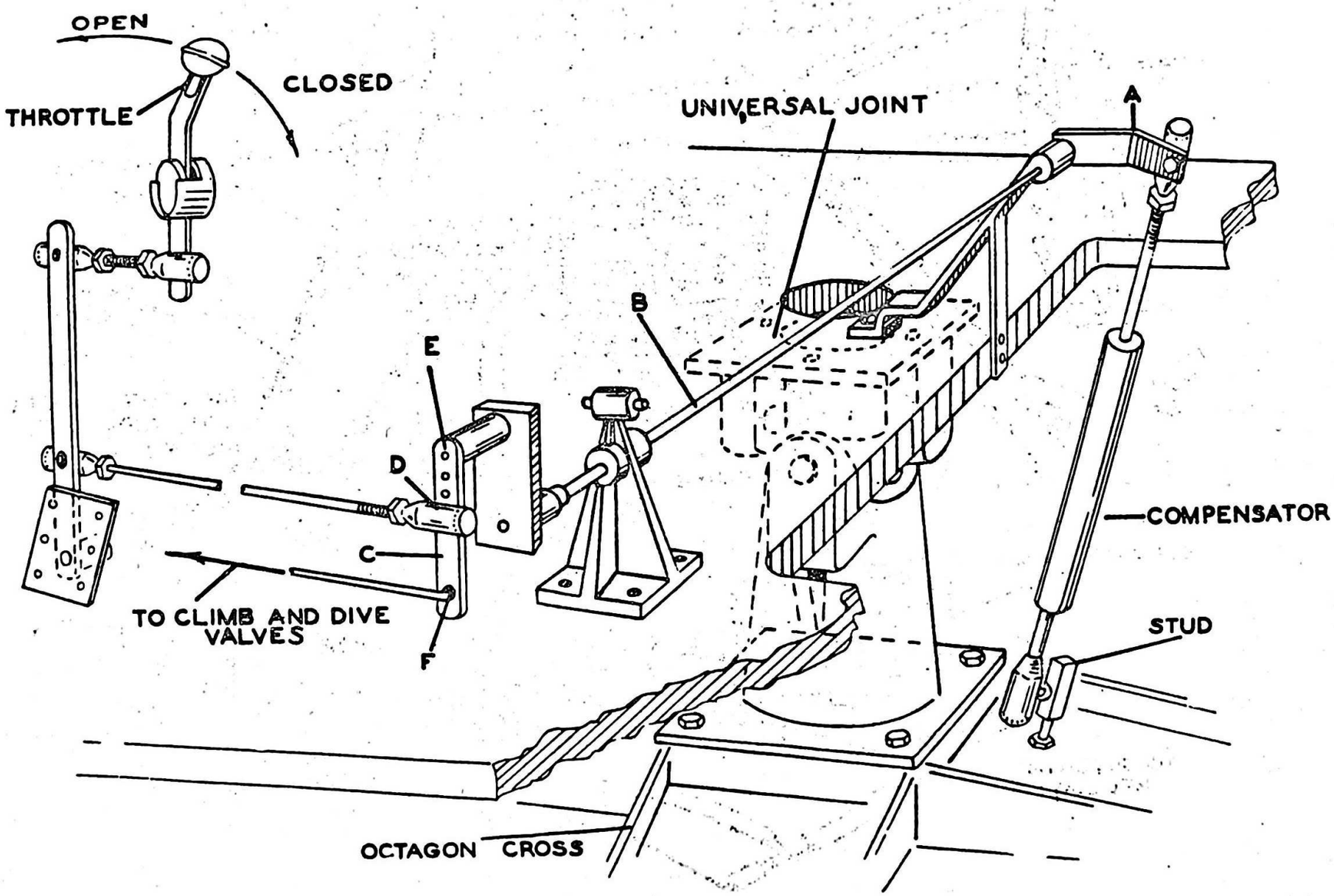


Fig 7 Pitch Action Assembly

the atmosphere vent. This closes the atmosphere vent and applies vacuum to the spin trip bellows thereby collapsing the bellows, causing the trainer to spin.

(e) As the stall valve pendulum moves away from the adjustable stop screw, the needle inside the valve body is turned away from the valve seat permitting a gradually increasing flow of atmosphere to pass through the valve, into the climb and dive tank, thus decreasing the vacuum pressure in the tank, causing the altimeter and vertical speed indicator to show loss of altitude indications. The period from the time the needle valve starts to open until the actual stall and spin occurs is know as the "mush" period. This is reflected on the altimeter and vertical-speed indicator by lowered altitude indications.

18. AUTOMATIC SPIN (See Fig.6)

(a) Automatic spin is accomplished by means of a bellows and latch mechanism, called the spin trip assembly, which is mounted on the shaft of the bank turner assembly. Three bellows are used - one to work the latch and the other two to provide energy for actuating the rudder valve when spinning.

(b) These parts are mounted on a hollow shaft which is free to turn on the solid shaft of the bank turner assembly Arm.(B) which is connected down through the fuselage floor to the octagon, is permanently attached to the hollow shaft on which bellows and latch are mounted. Arm (I) which carries the latch is also anchored to this hollow shaft, while arm (H) is secured by a setscrew to the solid inner shaft. As long as the latch is engaged with arm (H) the solid shaft is locked to the hollow shaft and the entire unit functions only to provide the automatic turn-with-bank feature.

(c) When the air speed falls below stalling speed, the pendulum, of the stall valve closes the atmosphere vent in the stall valve assembly, thereby applying vacuum to the line that leads to the small bellows which is linked to the latch (K). The vacuum closes this bellows and raises the latch out of the notch in arm (H). The hollow shaft is still held rigid by arm (B) but, with the latch disengaged, arm (H) and the inner shaft are free to turn.

(d) Of the top and bottom bellows, one or the other is always under vacuum. Assuming that, at the moment, vacuum is applied to the top one, this bellows then, is trying to close and, when the latch releases arm (H) the following action takes place: (i) The bellows (L) closes and through rod (N) and link (O) pushes arm (H) down, rotating the solid inner shaft. The bell crank on this shaft is swung forward and the walking beam pivoting at point (E), pulls the rudder valve wide open, causing the trainer to spin. (ii) If the bottom bellows (M) had been under vacuum instead of the top one, the same action would have taken place, except that the spin would have been in the opposite direction.

19. SPIN VALVE

(a) Control over which spin bellows shall be under vacuum is the function of the spin valve. This unit is simply a two-way valve which is connected on one side to the vacuum supply, and on the other to both spin bellows. It has an inverted pendulum and the position of this pendulum determines to which of the two bellows vacuum shall be applied. The pendulum normally falls toward the lowest side of the fuselage, but also can be thrown over by application of rudder through a fork which extends back from the rudder pedals.

(b) As long as air speed remains below stalling speed the small bellows controlling the spin trip latch will remain collapsed and the latch will remain raised where it cannot engage the notch in arm (H). During this time full application of rudder will throw the spin valve pendulum over and apply vacuum to the other spin bellows. As this bellows collapses it will swing the arm (H) past the latch and move the rudder valve around to fully open in the opposite direction. This will reverse the direction of spin but normal rudder control cannot be regained until normal air speed is recovered.

.../(c)

(c) To recover from a spin in the trainer, it is necessary to nose down - to regain normal air speed - and apply full opposite rudder. When normal air speed is recovered, the pendulum of the stall valve moves away from the atmosphere vent allowing atmosphere to enter, which decreases the vacuum to the small bellows. This bellows then expands (pulled open by springs) and returns the latch to its locking position. As full rudder is applied the spin valve pendulum is thrown over and the opposite spin bellows starts to collapse attempting to swing arm (H) past the latch. The latch, now being in its normal position, engages the notch in arm (H) and locks the solid shaft that carries the walking beam, restoring normal rudder control.

20. CLIMB AND DIVE VALVE

(a) The climb and dive valve assembly is located on the floor of the fuselage and consists of two separate valves, mounted and controlled as a unit. Both valves are connected to the line leading to the climb and dive tank and to the lines leading to the diaphragms of the Altimeter and vertical-speed indicator transmitter.

(b) The climb valve controls the amount of vacuum applied to the altitude system, while the dive valve controls the amount of atmosphere allowed to enter the system. Throttle movement or change in the nose-up or nose-down attitude of the trainer will open one or the other of these valves. When one is open, the other remains closed.

(c) When the climb valve is opened, air is drawn out of the climb and dive tank which reduces the pressure inside the tank below atmospheric pressure in the room. A condition is created inside the tank similar to the decrease of atmospheric pressure as altitude is gained in an airplane. This decrease in atmospheric pressure within the climb and dive tank acts on the diaphragms of the altimeter and vertical-speed indicator transmitters, causing increased altitude indications.

(d) When the dive valve is opened, atmospheric pressure being greater than the pressure within the tank, air will flow in. This reduces the vacuum inside the tank and the altimeter shows a loss of altitude. The rate that altitude is gained or lost, as shown on the vertical-speed indicator, depends directly on how far the climb or dive valve is opened.

(e) The climb and dive valve assembly is connected by a pitch action compensator down through the fuselage floor to a member of the revolving octagon. When the trainer is climbing or diving the floor of the fuselage assumes a slanting position while the octagon remains level. This causes movement of the pitch action shaft which opens either the climb or dive valve, depending on whether the trainer is nosed up or down. Since the push-pull connection from the pitch action shaft to the octagon is very nearly on the fore and aft centre line of the trainer, banking has no appreciable effect on the climb and dive valves.

(f) In the trainer, as in an airplane, the position or movement, of the throttle also affects altitude. This accomplished in the trainer by means of a walking beam on the bell crank of the pitch action shaft. A differential is thus provided between throttle movement or position and nose up or down movement of the trainer and the resultant motion is transmitted to the climb and dive valves.

(g) Each of these valves contains a valve needle and a sleeve into which the needle is silver soldered. The needle has a small diameter for a proportion of its length, to give it flexibility, and is self-centering in the valve seat. The needle sleeve is threaded and screws into the body of the valve.

(h) Plain shut-off type valves (limit valves) are provided at one end of both the climb and dive valves. These limit valves are adjustable to restrict the flow of air to the desired rate of climb and descent.

21. REGULATING BELLOWS.

(a) Regulator bellows are used to control the amount of vacuum applied to the air-speed indicator transmitter diaphragm and to the

.../trachometer.

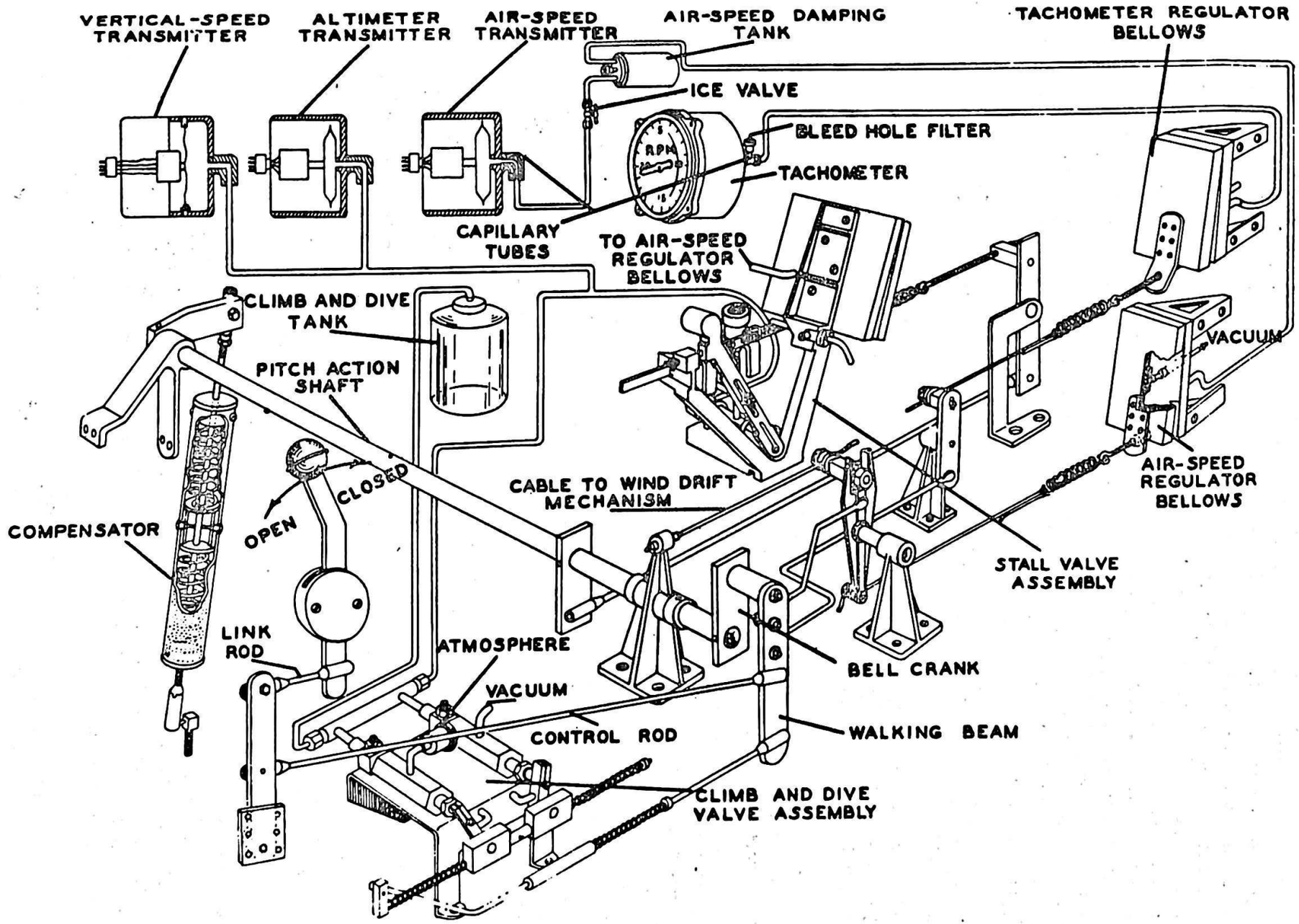


Fig 8 *Instrument Control (S hematic)*

tachometer. These regulator bellows are connected through coiled springs to the walking beam on the pitch action shaft, so that the effects of nose-up or nose-down attitude of the trainer, combined with the throttle setting, result in correct indications of air speed and engine speed.

(b) Fitting (A) is connected by tubing directly to the main vacuum supply - (B) is connected by tubing through a small damping tank to the air-speed transmitter, or connected directly to the tachometer. (Identical bellows are used for both instruments).

(c) When the trainer is turned on and vacuum applied to the bellows at (A), air is drawn out and the bellows starts to collapse but the coiled spring (C) is tending to hold it open. Air continues to be drawn out until there is sufficient vacuum created to overcome the tension of the spring. As the spring tension is overcome and the bellow closes, the needle valve (D) shuts off the supply of vacuum. The damping tank in the line to the airspeed transmitter has a small bleed hole equipped with a filter. As air leaks in through this bleed hole the vacuum in the bellows decreases until it can be overcome by the spring, which then pulls the bellows open slightly. The needle valve will be opened only enough to permit the passage of just enough air to balance the leak in the damping tank and this condition will remain until the pull on spring (C) is changed.

(d) The air speed indicator and the tachometer are simply vacuum gauges and indicate the pressure differential inside their respective regulating bellows.

(e) Since the pull wire (E) is linked to the walking beam of the pitch action shaft, any change in trainer attitude or Throttle Setting will vary the pull of spring (C) on the bellow.

LINK TRAINER INSTRUMENTS

22. TELEGON SYSTEM OF REMOTE INDICATION

(a) The KOLLSMAN telegon system of remote indication is used in the trainer in order that identical instrument readings may be shown on duplicate sets of indicators.

(b) The remote indicating system consists of a single transmitting unit, located at the source of measurement, and two indicating units, one of which is mounted on the instrument, panel in the trainer fuselage and the other at the instructor's desk.

(c) The transmitter is a Kollsman telegon unit which is actuated by an instrument mechanism similar to standard aircraft instruments.

(d) The indicator consists of a telegon unit which is structurally identical with the transmitter unit and which carries the instrument dial and hand.

(e) The following instruments are operated by the remote indicating system (i) Altimeter, (ii) Airspeed indicator, (iii) Vertical-speed Indicator.

(f) Nine telegon motors are used in the trainer, each remote instrument requiring three telegons for its operation.

23. DESCRIPTION OF A TELEGON UNIT

The unit consists of a spool assembly, four terminals and two terminal insulators, a shell, and two end bells. The spool assembly contains the shaft assembly (K), the primary coil (M) and the phase windings (F-F1). The four terminals are connected to the primary coil and the phase windings.

.../Principle of

PRINCIPLE OF OPERATION:-

(1) The primary coil M is energized from an external alternating current source, and the resulting flux magnetizes the outer section of the shaft assembly K and the vanes. As the shaft assembly of the transmitting unit is rotated, the corresponding induced magnetic field surrounding the vanes is also rotated. This field pattern induces an E.M.F. in the phase windings (F and F_1), the voltage in each pase being determined by the geometric alingment of the rotor to the phase windings. The voltages thus induced give rise to proportional currents, which flow in the phase windings of both the transmitting and the indicating units setting up a flux pattern in the indicating unit identical to the pattern in the transmitting unit. The field flux in the indicating unit reacts with the vanes (which are magnetized from the same source as the transmitting unit), causing the shaft assembly to assume the same angular position as that of the transmitting unit.

(2) The power for the entire Telegon system in the Trainer is supplied by an oscillator which operates from a 110 volts, 50 or 60 cycles source, and draws approximately 0.9 amps. This oscillator energizes the telegon units and each unit draws 1.25 watts at 80 volts and 700 cycles.

23A. VIBRATOR MOTORS

(a) Three of these units are used in the trainer, located as follows:-

One on the instrument panel in the cockpit, one on the panel behind the cockpit in the rear of the fuselage and one in the remote instrument cabinet on the instructor's desk.

(b) Each unit consists of a small induction motor supplied by 110 volts A.C. and is made to provide vibration by mounting two small adjustable fly wheels in an unbalanced position on the motor shaft.

(c) Their purpose is to provide sufficient vibration for smoothing out the operation of the instruments.

24. TELEGON OSCILLATOR

(a) The function of this Unit, which is located in the base of the trainer, is to supply 700 to 800 cycle current for the remote indicating instruments. It utilises a type 83V. rectifier tube. It has three 6L6G tubes, one as an oscillator and the other two as amplifiers to increase power to the necessary level for proper operation of the instruments.

(b) Power supply to the telegon oscillator should be 110 to 115 volts, 50 to 60 cycles frequency. The output of the unit should be 80 to 90 volts, 700 to 800 cycles per second. The voltage must be measured under full-load condition with all remote instruments properly connected. Voltage can be regulated by adjustment of the sliding contact on appropriate resistance.

DESCRIPTION OF OSCILLATOR

The unit has three circuits, viz:- Rectifying, Oscillating and Amplifying.

RECTIFYING CIRCUITS

110 volts A.C. is supplied through a 3 amp fuse to the primary of a transformer which has three secondary windings.

1. The main circuit winding
2. Oscillating and amplifying valve
3. Filament heating winding
4. Rectifying valve heating winding

.../The main

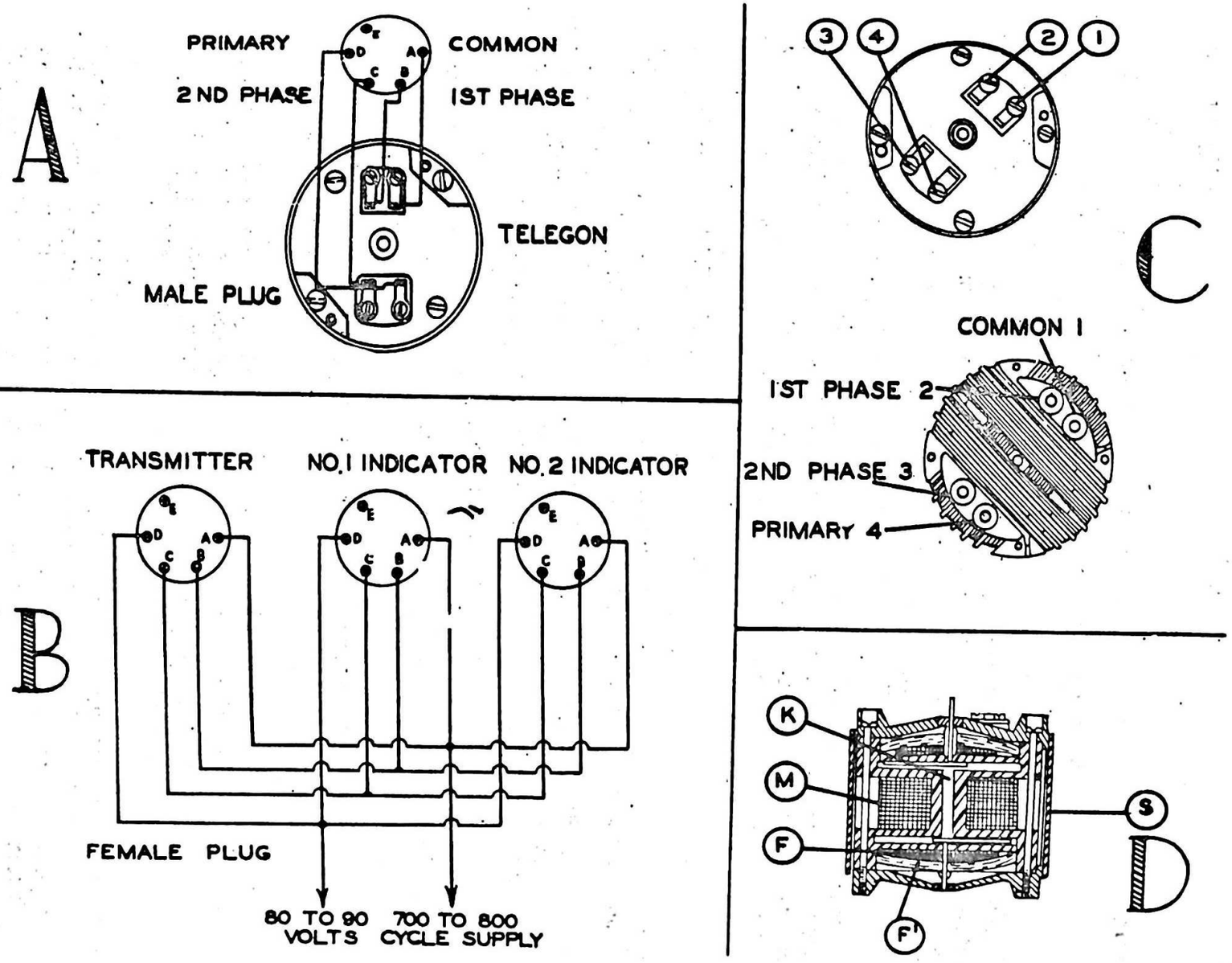
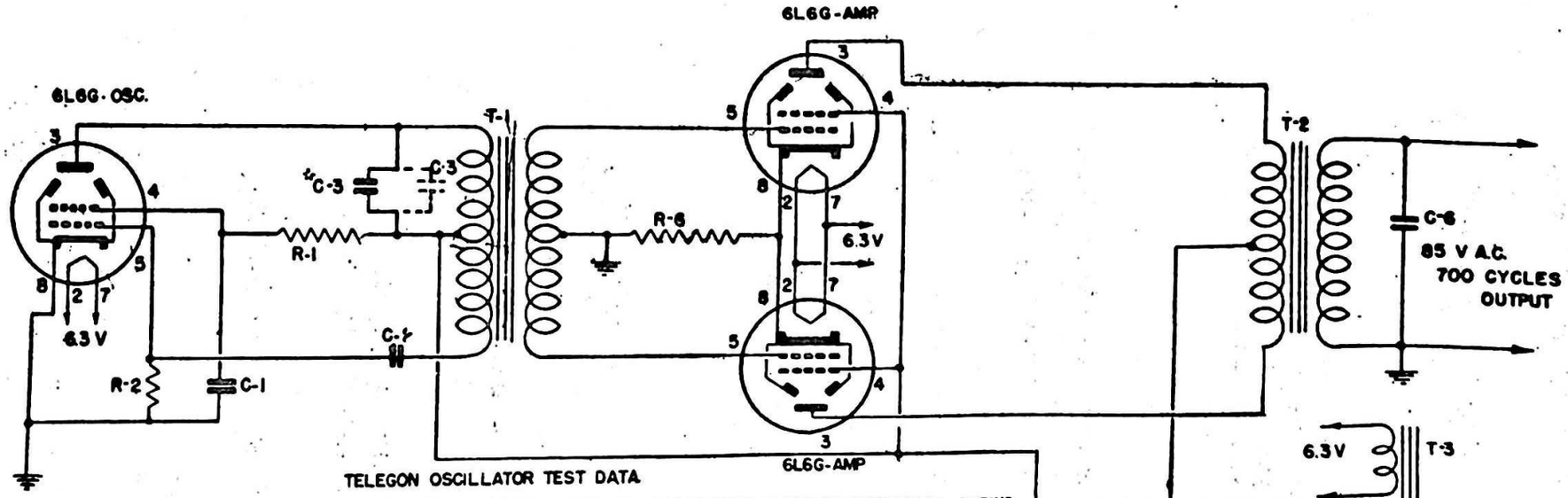


Fig 9 a Telegon Unit



TELEGON OSCILLATOR TEST DATA

THESE VOLTAGE TESTS MUST BE MADE WITH EXACTLY 115 VOLTS INPUT TO THE OSCILLATOR WITH ALL INSTRUMENTS PROPERLY CONNECTED. DURING NORMAL OPERATION, VOLTAGES SHOULD NOT VARY MORE THAN ±5%. VOLTAGE OF MORE THAN 10% SHOULD BE CAREFULLY INVESTIGATED.

NORMAL WORKING VOLTAGES BETWEEN TUBE ELEMENTS AND GROUND.

OSCILLATOR TUBE

PRONG	NO. 3	TO	GROUND,	220 VOLTS	D.C.
"	NO. 4	"	"	65 "	"
"	NO. 5	"	"	-28.5 "	"
"	NO. 2	"	NO. 7	6.3 "	A.C.

AMPLIFIER TUBE

PRONG	NO. 3	TO	GROUND,	345 VOLTS	D.C.
"	NO. 4	"	"	220 "	"
"	NO. 5	"	"	0 "	"
"	NO. 7	"	"	6.8 "	A.C.

RECTIFIER TUBE

PRONG	NO. 1	TO	GROUND,	355 VOLTS	D.C.
"	NO. 2	"	"	315 "	A.C.
"	NO. 3	"	"	315 "	"
"	NO. 2	"	NO. 3	690 "	"
"	NO. 1	"	NO. 4	4.9 "	"

RESISTANCE BETWEEN TUBE ELEMENTS AND GROUND. OSCILLATOR OFF

OSCILLATOR TUBE

PRONG	NO. 3	TO	GROUND,	200,000	OHM
"	NO. 4	"	"	700,000	"
"	NO. 5	"	"	400,000	"

AMPLIFIER TUBES

PRONG	NO. 3	TO	GROUND,	[illegible]	OHM.
"	NO. 4	"	"	[illegible]	
"	NO. 8	"	"	500	"

NOTE-C-3*

THIS CAPACITY IS ADJUSTED AT THE FACTORY TO TUNE THE OSCILLATOR FREQUENCY TO BETWEEN 700 AND 800 CYCLES. THIS IS A COMBINATION OF TWO CONDENSERS, THE COMBINED CAPACITY OF WHICH MAY VARY TO AS MUCH AS .05 [illegible]

ONE END OF RESISTOR R-7 TO GROUND, 0; OTHER END TO GROUND, 35 VOLTS A.C. WITH OSCILLATOR ON.

CONDENSERS

C1;	.05	MFD	1000 V.
C2;	.001		400 V.
C3;	.05		1000 V. (PAPER)
C4;	16		450 V.
C5;	.4		1000 V (OIL)
C6;	.9		600 V.

RESISTOR

R1;	500,000	OHM	1 WATT
R2;	400,000	"	1 "
R4;	200,000	"	1 "
R5;	10,000	"	25 "
R6;	900	"	50 "
R7;	750	"	50 "

Fig. 9b Wiring Diagram, Telegon Oscillator

The main winding is centre tapped and taken to earth through a 750 ohm variable regulating resistance (R.7).

The valve type 83V is a full wave rectifier and supplies D.C. at the pressure of 345 volts to earth, to a centre tapping on the primary of the output transformer (T.2) through which is applied to each anode of the two amplifying valves.

The rectifier current is also taken through a resistance (R.5) to the screens of the amplifying valves and to the centre tapping of the oscillation transformer through which is fed to the anode of the oscillating valve.

The screen of the oscillator valve is also supplied by the same feed wire through a resistance (R.1) which serves to reduce the voltage and condenser (C.1) acting as a by-pass. The condenser (C.5) acts as a smoothing unit and the resistance (R.4) limits the peak voltage.

AMPLIFYING CIRCUIT

The secondary of the oscillation transformer is centre tapped to earth and has its outside connection taken to the grid of the amplifying valves. The cathodes of the valve are connected to earth through the resistance (R.6).

The grids of the valves are alternately positive and negative so that when anode current is rising to maximum in one valve, it is falling to minimum in the other. Thus a fairly constant current is being taken from the rectifying valve to the centre of the output transformer primary winding. The output transformer steps down the oscillating voltage to 90 volts R.M.S. The secondary winding has I.M.F.D. condenser across it and its output is taken to the 9 telegon motors, the total load being about .36 amps.

25. TACHOMETER

The tachometer indicates engine speed and is operated by vacuum through a regulating bellows which is controlled by the throttle and by movements in pitch of the trainer.

2. Vacuum is applied to the regulating bellows which tend to contract and shut off the vacuum supply by drawing a tapered needle valve on to its seating inside the bellows.

3. Opening the throttle or nosing the trainer down applies tension to a regulating spring connected to the moveable side of the bellows and so pulls the valve from its seating.

4. Vacuum is thus applied through the bellows and the outlet pipe along a copper pipe line to the case of the instrument.

5. A small hole is drilled in the pipe line allowing a constant leak from atmosphere and so providing the necessary flow in the system.

6. A fine bore choke is connected in the pipe line at the junction to the instrument casing and has the effect of reducing the sensitivity of the instrument.

7. The Capsule of the instrument is open to atmosphere and tends to expand when the pressure inside the instrument case is reduced.

8. Movements of the Capsule are followed by a bell crank lever which actuates a toothed sector meshed with the handstaff pinion and so rotates the hand of the instrument.

9. Adjustments can be made at each end of the connection between the bellows and the leverage system, fine adjustments being made by a knurled nut at the bellows end.

10. A weak regulating spring has the effect of preventing the readings dropping to the required valve when the throttle is closed. The opposite effect is produced by a spring which is too strong.

11. A small hole in the pipe line should be kept clear of dust, etc., by means of a bristle from a brush or some similar object which will not tend to enlarge the orifice.

26. AIR SPEED INDICATOR

The mechanism of the airspeed indicator is operated by vacuum through a regulating bellows in the same way as the tachometer.

2. A small tank is fitted in the pipe line to provide the necessary lag in the indications, a calibrated leak hole is drilled in this tank.

3. The vacuum is applied through a choke to the diaphragm of the instrument which contracts and is followed by a bell crank lever which operates a toothed sector and so turns the instrument hand.

4. A hairspring keeps the bell crank lever in contact with the diaphragm.

5. The hand does not indicate the airspeed direct on a dial but is coupled to the rotor of the transmitter telegon motor, which transmits the hand movements electrically to the desk and dashboard airspeed receivers.

6. The airspeed should be adjusted to read 160 mph with the trainer level and the throttle in cruising position.

7. Adjustments are made in asimilar way to those described for the tachometer.

27. VERTICAL SPEED TRANSMITTER

This assembly is located in the rear of the trainer and consists of a large tank which is divided into two compartments by means of a metal diaphragm.

2. One compartment houses the mechanism of the instrument and telegon motor, the leads from the latter being taken into a socket in the rear cover of the tank. A shaft having a small gear wheel on one end which engages with a large wheel on the casing of the telegon motor is also brought through the cover of the tank and is fitted with a knurled aluminium knob which can be rotated to adjust the zero indicator of the V.S.I.

3. The shaft passes through a gland in the cover which prevents leakage.

4. A union in the front cover of the other compartment is connected through pipe line to the expansion tank.

5. A duct between the two compartments is partially blocked by a metal rod screwed into the front end cover so that a small leak exists between both sides of the diaphragm. When the trainer is climbed, the reduced pressure in the expansion tank is applied to one side of the diaphragm and as the leak to the other side is very small the change of pressure will only be slowly passed through. The diaphragm is then distended and the movement is followed by a bell crank lever, rack and pinion to turn the rotor of the telegon motor. When the trainer resumes level flight and the climb and dive valves are both closed, the pressure on either side of the diaphragm are equalised through the leak and the diaphragm resumes its normal position and the pointer of the instrument should indicate zero. The zero adjustment should only be used when the trainer is in cruising position, i.e. with the climb and dive valves closed.

.../When the

6. When the trainer is dived or the throttle is closed, atmospheric pressure is allowed to pass through the dive valve to the expansion tank. The increasing pressure in this tank is applied to one side of the diaphragm to the V.S. transmitter causing it to be distended in the opposite direction to that obtained during climb. The movement of the diaphragm is taken through the instrument mechanism to turn the rotor of the telegon motor. Rotating of the rotor of the transmitter telegon causes the rotors of the two receivers telegons to turn synchronously and the pointers attached to the spindles of the receivers indicate on a calibrated dial the vertical speed of ascent or descent depends on the indicated altitude of the trainer, the vertical speed on ascent falling off as height is gained and the rate of descent decreasing as the altimeter approaches zero.

7. To facilitate landing practice the altimeter is normally given an initial se' ing of 500 ft. below zero with a barometric pressure of 1013 millibars. to reduce the sluggish indications on the altimeter and the V.S.I. as the depression in the expansion tank approaches atmospheric pressure.

28. ALTIMETER MECHANISM

The mechanism of the altimeter is mounted on a panel in the rear of the fuselage and consists of a metal capsule, a bell crank lever, rack and pinion and multiplying gears.

2. The capsule which is about 5" diameter is fitted with a union through which it is connected by pipe line to the main expansion tank.

3. The mechanism is fitted with a hairspring which keeps one arm of the bell crank lever in contact with the capsule, a roller is provided for the lever to move on, to reduce friction to a minimum.

4. When the trainer is climbed, vacuum is applied through the climb valve to the main expansion tank and through the pipe line to the altimeter capsule, causing it to contract.

5. This movement of the capsule is followed by a bell crank lever, and allows the toothed rack to move and so turn the pinion which it is meshed. The pinion is integral with a larger toothed wheel which meshes with the hand staff pinion and so gives the multiplying effect to the pointer movement.

6. The pointer does not indicate height directly on a dial, but is joined by means of a forked coupling to the rotor of a telegon motor.

7. The mechanism of the altimeter, the capsule and the telegon motor form one complete unit which is termed the altimeter transmitter.

29. ADJUSTMENT OF ALTIMETERS

If the supply voltage to the 800 cycle oscillator is cut off, the pointers of the remote indicating instruments remain stationary in the positions they occupied when the oscillator ceased to function.

2. The oscillator circuit should therefore not be opened until the altimeters indications are below zero, if however this is done or if the power supply fails whilst the altimeters are shewing a height above zero, it will be necessary to adjust both altimeters to the correct zero setting.

.../3.

3. When power is again available and the oscillator is switched on, the pointers of the V.S.I. and A.S.I. and the long pointers of the altimeters will synchronise themselves with the transmitter pointers. The short pointer of the altimeter will, however, indicate the height in thousands of feet at which the oscillator supply voltage failed.

4. It is then necessary to adjust the altimeters to the current zero setting before the trainer is used again, the procedure is as follows:-

METHOD

With the oscillator on, rotate the knob on the instrument case until an indication of 500 ft. below zero is obtained.

5. Loosen the small screw on the left of the knob until the screw head is clear of the case, then move it sideways to the left.

6. Pull the knob outwards and rotate it. This will turn the barometric scale without moving the pointers and it should be rotated until a reading of 1013 millibars is obtained. The knob should then be allowed to return to its normal position and the small screw should be moved to the right and tightened.

30. TURNING INDICATOR MK.1A

SPECIAL FOR LINK TRAINER.

The rotor is mounted awartships in a gymbal ring which is pivotted fore and aft in the instrument case.

2. A spring is connected between the case and the centre line of the inner ring to control the movement of the latter,

3. When the machine to which the instrument is fitted turns in a horizontal plane, a torque is applied to the outer ring (the case) of the gymbal system which precesses the inner ring to a point where the precessing torque is balanced by the controlling force of the spring.

4. This movement of the inner ring is made to operate a pointer which indicates on a dial, the rate of turn.

5. Damping is provided by an air dash pot in which a piston is made to oscillate by a toothed quadrant attached to the inner ring.

6. A second pointer is provided to indicate side-slip.

7. The turn indicator pointer is fixed directly to the gymbal ring.

8. The slip indicator pointer is slotted at its lower end and engaged with a pin on the upper end of a pivotted pendulum which provides gravity control.

9. In the instrument fitted to the Link Trainer a slight alteration is embodied in order to obtain the correct indications during flat or incorrectly banked turns.

10. This modification consists of pivotting the slip pointer on the turn indicator pointer so that during a flat turn, the pivot is moved by the turn pointer, whilst the bottom of the slip pointer is held by the pendulum and the pointer indicates side-slip.

11. During a banked turn, the relative movement between the pendulum and the slip pointer tends to bring the latter to the centre position.

12. The instrument is operated by vacuum through an adjustable regulator bellows which is fitted behind the dashboard in front of the trainer.

31. NORTHERLY TURNING ERROR

In the Northern Hemisphere the NORTH seeking end of the magnetic system of the compass dips down slightly and the C.G. of the system is drawn away from the vertical axis and gravity just balances the dip.

2. Thus when an aircraft is flying on an even keel, the magnetic system will not be parallel to the cover glass of the compass and the C.G. of the system will not be immediately below the point of support.

3. When an aircraft on a northernly course turns East or West, centrifugal force acting on the C.G. of the Magnetic system will cause the system to turn with the aircraft and so understimate the turn or even indicate a reverse turn as the compass card will still have tendency to continue the turn after the aircraft has ceased turning.

4. In turning from a Southernly heading to East or West the tendency is to over estimate the turn.

5. Turning error is simulated on the Link Trainer by means of the compass deflector system which in late models is operated electrically.

32. EIECTRICALLY OPERATED DEFLECTOR SYSTEM

The deflector consists of two coils mounted under the compass and connected through contacts on the rudder valve to a variable resistance which is supplied with current from the 12.V transformer behind the trainer dash-panel through a metal rectifier.

Operation of the rudder valve causes two of the contacts to touch and a circuit is completed through one of the deflector coils making the latter an electro magnet and deflecting the compass system.

The amount of deflection can be adjusted by the variable resistance and the point at which deflection occurs can be advanced or retarded by the adjustment of the contacts attached to the lower half of the value.

33. AUTOMATIC RADIO COMPASS

(a) The Automatic Radio compass used in the Trainer is a simulated method of providing the students with radio compass bearings.

(b) Movement of the radio compass indicator hand is obtained by one or both of two means, through teletorque motors located in the base of the Trainer, by Trainer rotation and by rotation of the knob on the desk control unit.

(c) Four teletorque motors from the basis of the system, as follows:-

One transmitter teletorque is located in the control unit at the instructor's desk and is provided with a suitable vernier drive and ozimuth scale. Rotation of the control unit knob rotates and/or positions the armature of the receiver teletorque motor, (the lower of the two teletorques in the trainer base).

34. FUEL GAUGE

(a) The fuel gauge is operated by a clockwork mechanism. It requires approximately one hour to run down after being wound up with a key to its full capacity of 50 gallons.

(b) When the pointer hasrun down to the zero mark, a switch is automatically opened. This switch is wired in series with the Trainer main switch, so that when the gauge reads zero (empty) the Trainer is automatically turned off.

.../(c)

(c) A key switch is provided, located just below the ignition switch and is wired to bridge the fuel gauge switch. When this key switch is closed, the fuel gauge switch has no effect on Trainer operation.

35. AUTOSYN MOTOR 32 VOLTS. A.C. SINGLE PHASE. (TELETORQUE)

The stator is made up of laminations in which helical slots are cut and is wound to form three pairs of poles 120 degrees apart. Connections are brought out to three terminals marked 1, 2 and 3 which are joined by cables to terminals on the other autosyn motor. The armature has one end of its winding earthed whilst the other end is brought out to an insulated pin the end of the armature shaft. A spring leaf contact bears on this pin and connects with a terminal marked "A", the earthed terminal is marked "G".

OPERATION

The armature is supplied with current from the A.C. supply through a transformer at a pressure of 32 volts. The flux due to this current induces a field in the stator the field rotates when the armature is turned.

As the stator coils are connected to similar windings in the other autosyn motor which also has 32 volts across its armature, the field of the second motor will rotate and cause the armature to turn with it.

36. TELECHRON SYNCHRONOUS MOTOR

50-60Cycles. 100-125 Volts. 4 watts

CONSTRUCTION

A rectangular yoke of laminated soft iron is shaped in the middle of one of its longer sides to form pole pieces. These pole pieces are split down the centre so that four pole faces are formed. On two of these pole pieces, located diagonally opposite, copper discs are fitted.

An inducation coil is wound around the other long side of the yoke and is connected through slip rings and a tumbler switch to the 100 volts supply.

A cylindrical brass casing is made to fit tightly between the pole pieces and this contains a rotor and reduction gearing and on the end of a protruding spindle is a gear wheel.

OPERATION

When the tumbler switch on the automatic recorder is in the "ON" position, the induction coil on the laminated yoke is connected to the 110 volt supply.

The current due to this voltage induces magnetism of alternating polarity in the pole pieces and the copper discs on the two half pieces have eddy currents induced in them. These eddy current cause the magnetism in the pole piece to which they are attached to lag behind the main magnetic field and so produce a rotating field. The rotating field acts on the rotor in the brass casing and turns it at synchronous speed.

.../Automatic

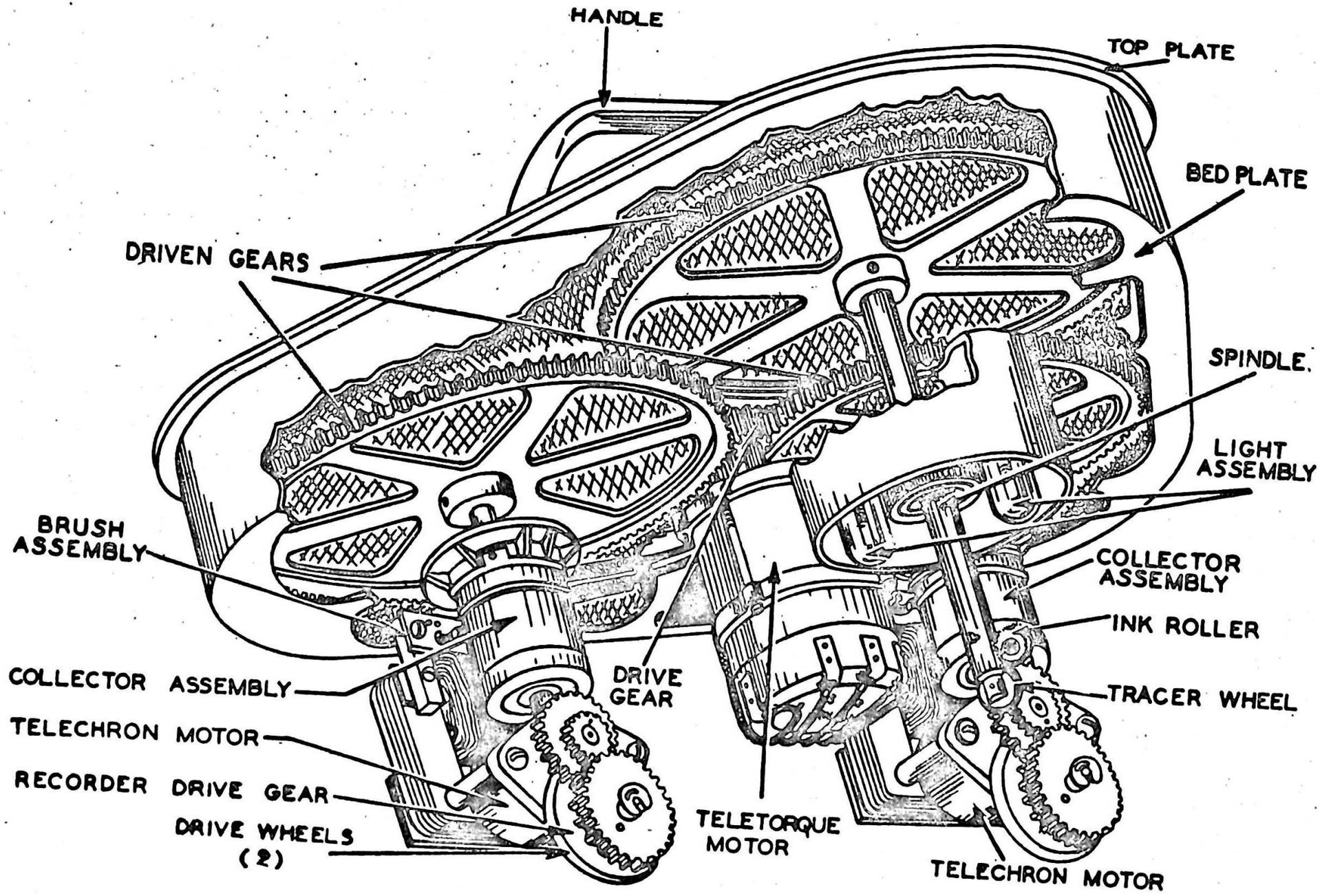


Fig 11. Automatic Recorder (Schematic)

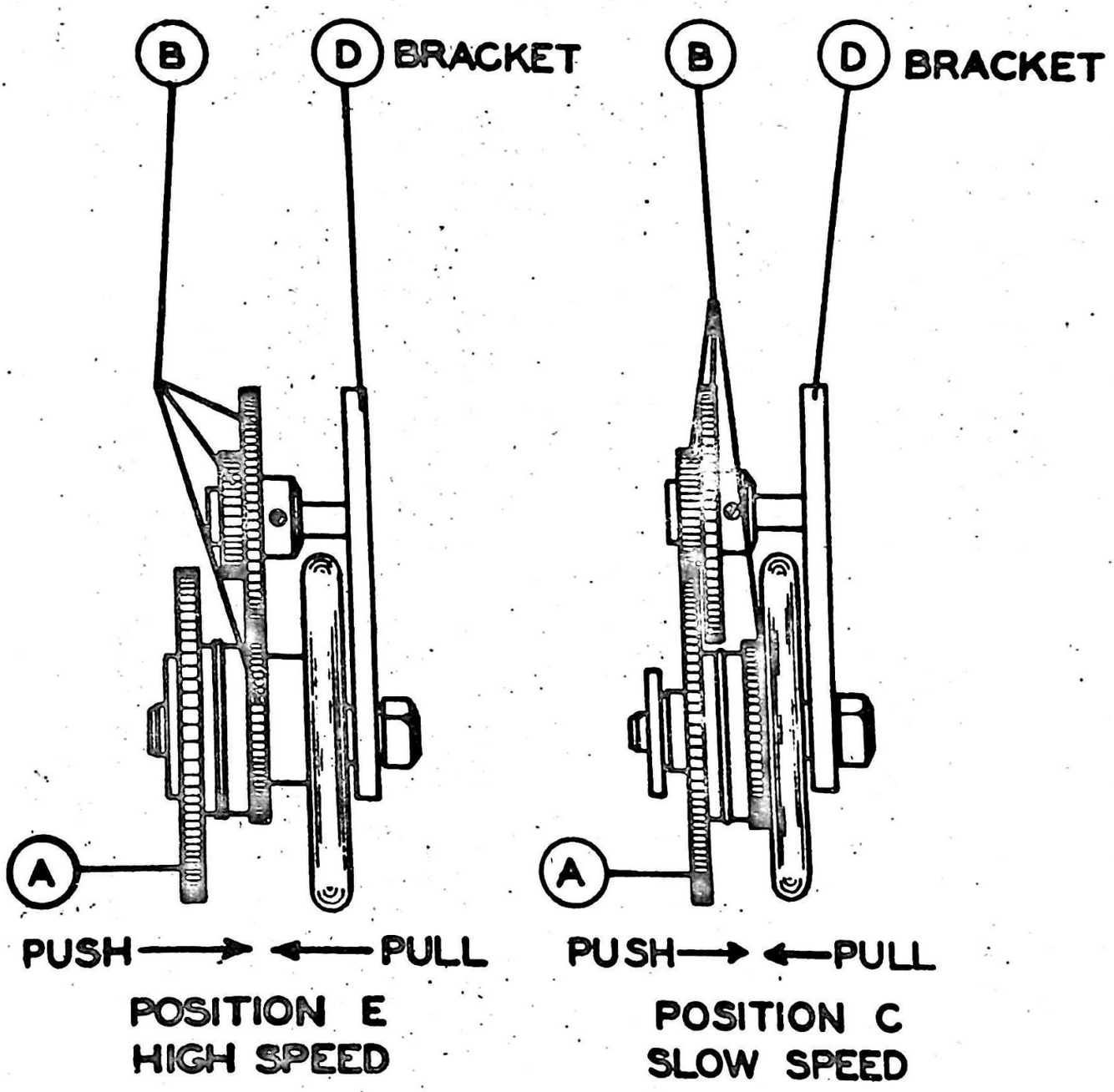


Fig 10 Automatic Recorder Gear Shifting Device

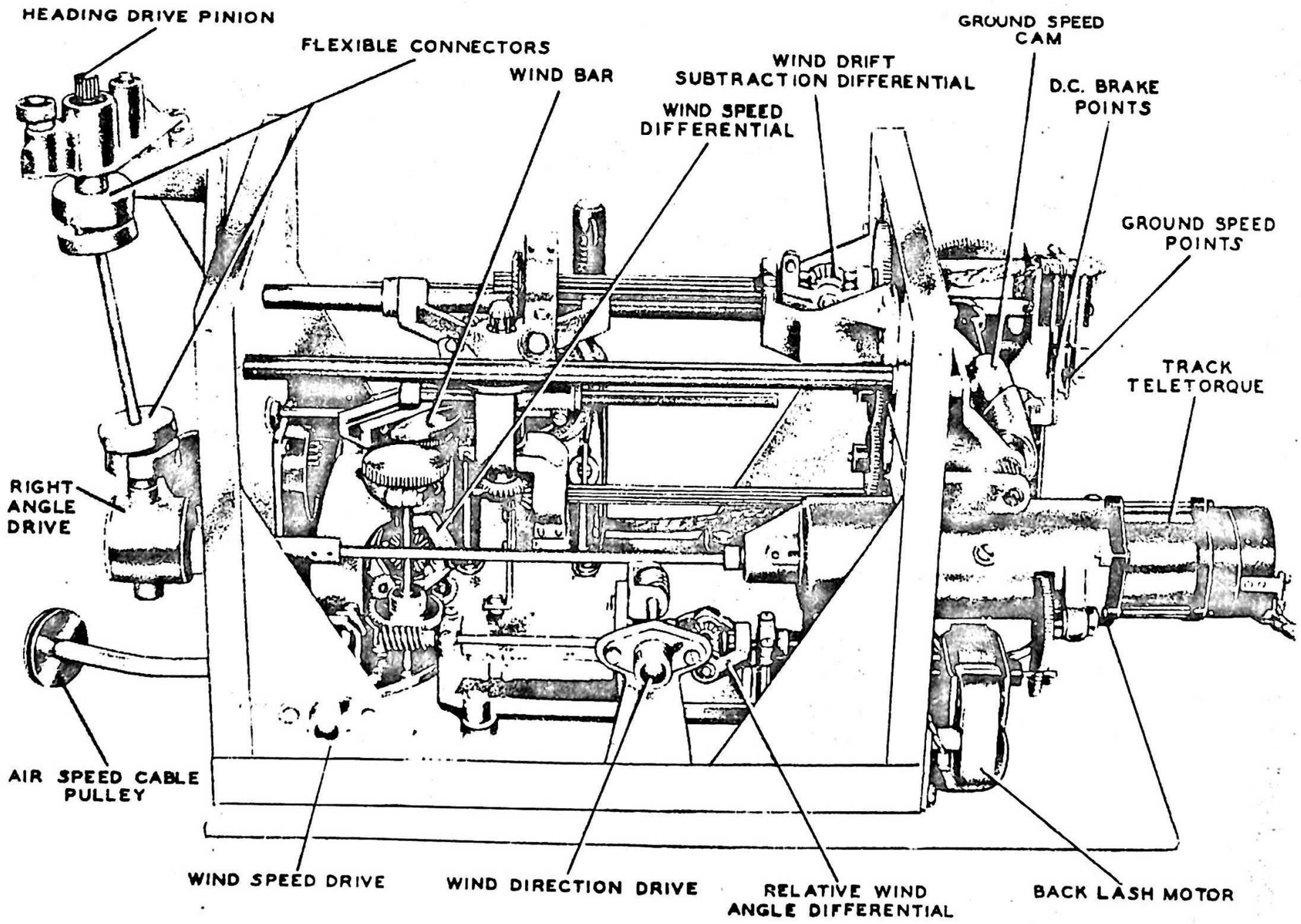


Fig 12 Wind Drift Mechanism

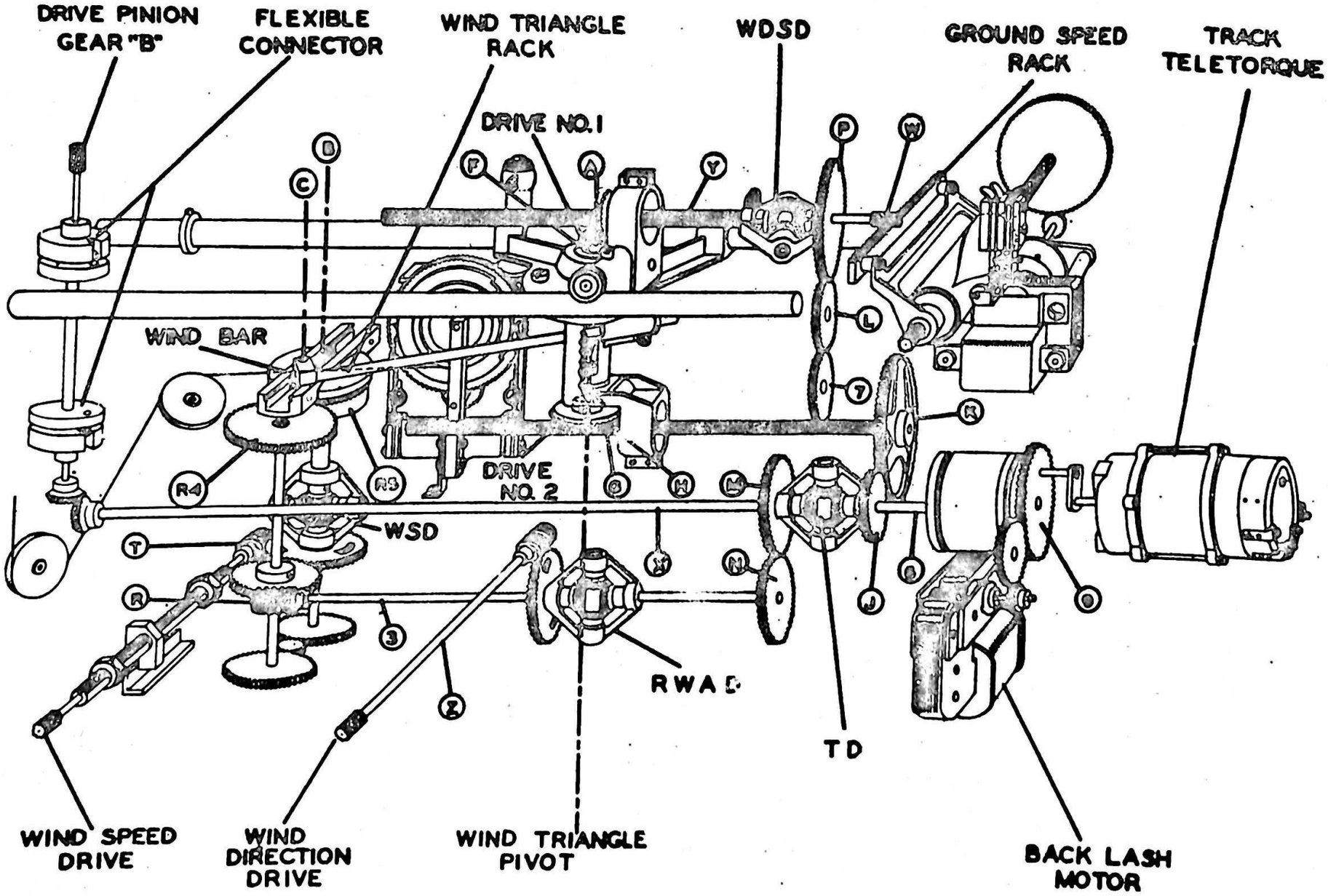


Fig. 13. Wind Drift Mechanism (Schematic)

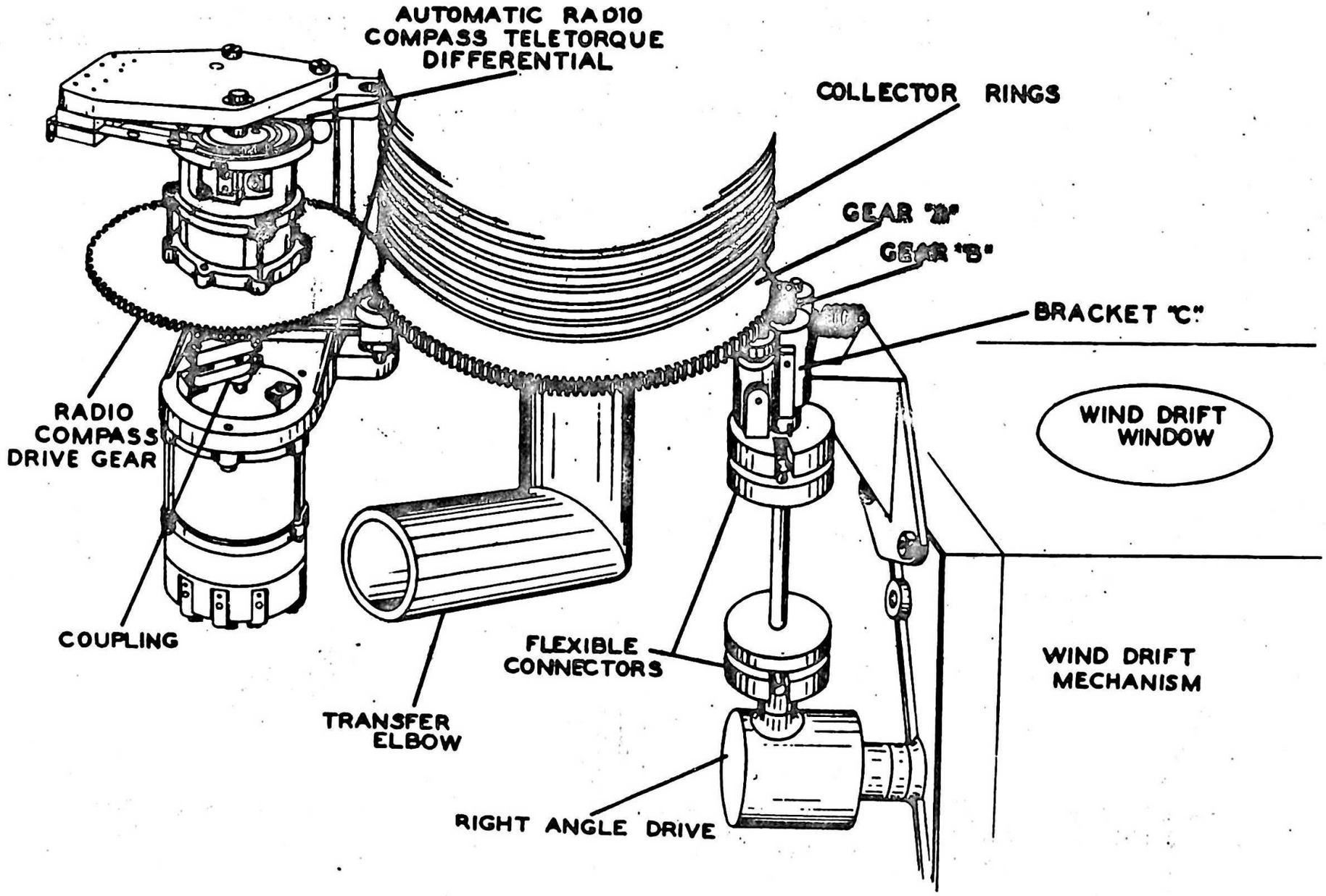


Fig 14 Automatic Recorder and Automatic Radio Compass Drives

37. AUTOMATIC RECORDER

(a) The automatic recorder travels over the chart or map on three wheels. Two of these wheels are drivers and the third is an inking wheel which leaves an inked track on the chart. Two synchronous Telechon motors are geared to the driving wheels and provide forward travel of the recorder.

(b) With the aid of a gear shifting device the drive gears of the motors can be shifted from a low, speed to a high speed. The low speed gears (0.8 inches per minute at cruising speed) are used for ordinary instrument and radio orientation problems, while the high speed gear drive (3.2 inches per minute) is used for instrument landing problems. It is possible to change from the low speed gearing to the high speed gearing without removing the motors.

(c) When shifting the gears, make sure that both gears are engaged, as there is a neutral position between each gear ratio. Be sure both motors are set to the same tracking speed. Otherwise the recorder will not track properly.

(d) Directional control is obtained with a teletorque motor located in the centre of the recorder. Each of the three wheels is attached to a vertical shaft. At the top of each shaft is a large gear. All three of these large gears mesh with the small pinion gear on the teletorque motor. Thus, when the teletorque motor is causes to rotate the three large gears and their shafts also rotate and steer all three wheels. It will be seen from this that the three wheels should always be headed in the same direction.

(e) A similar teletorque motor, controlled through the wind drift mechanism is located in the trainer base and geared to the vertical main shaft of the trainer. It is characteristic of the teletorque motor that when the one in the base is rotated (by turning motion of the trainer) the teletorque in the records duplicates the turn. This steers the recorder and causes it to faithfully trace on the chart the turns made by the student.

(f) When the trainer mains is switched on the teletorque motors "come alive" and the teletorque motor on the recorder will line up with the one in the base. Between the teletorque pinion gear and the large gears in the recorder there is a gear rati of 12 to 1. Consequently, when the teletorque "comes alive" and line up with each other, the large gears of the recorder will jump to the nearest of the 12 headings.

38. WIND DRIFT MECHANISM

(a) Purpose. The wind drift mechanism serves to introduce the effects of various wind directions and velocities on trainer heading out ground speed at cruising and other air speeds, as traced by the recorder.

(b) Effect on Recorder Movement: In order that the pilot working in the trainer may be subjected to the same conditions as he would be in the Air, it is necessary to provide simulated wind conditions. These conditions appear in the behaviour of the Recorder. The movement of the recorder on the chart simulates travel over the ground under wind conditions. This movement is governed by the wind drift mechanism located in the base of the Trainer. The mechanism consists of an assembly of gear trains so arranged that when the various elements of the wind drift problem are led into it, the output is track and ground speed.

.../(c)

(c) Wind direction and wind velocity dials: In operation, wind direction and wind velocity are applied to the trainer heading and air speed by the instructor, either before or during a problem. This is accomplished by turning the wind velocity and wind direction cranks on the right hand side of the desk to the desired settings. The wind velocity dial at the desk goes from a zero setting to 60 miles per hour, the wind direction from zero through 360°.

(d) Conditions to be represented in terms of the Wind triangle

(i) The wind drift mechanism is mechanical computer which constantly solves the wind triangle automatically. Into it are put the following:-

(a) Heading - by trainer rotation.
(b) Air Speed - by throttle setting and trainer attitude.
(c) Wind direction - manually.
(d) Wind velocity - manually.

Out of it came track and ground speed.

(ii) The three sides of the wind triangle are usually drawn and labelled for graphic solution in the following form:-

(a) Heading and air speed.
(b) Wind direction and velocity.
(c) Track and ground speed.

(iii) All are subject to change, both in direction and length. However, in the wind triangle used in the wind drift mechanism one of the sides (AB) is fixed in direction and, for mechanical reasons, the wind triangle elements are arranged as follows:-

(a) Air speed (AB)
(b) Wind speed - (BC)
(c) Relative wing angle - (ABC)

(iv) The relative wing angle is the angle between the heading and the wind direction. From these are produced the ground speed (CA) and the drift angle (OAB).

(v) To illustrate how the wind triangle in the wind drift mechanism meets the necessary conditions; and aircraft in flight on a North heading at 160 M.P.H. air speed encounters a wind from the East blowing at 60 M.P.H. The relative wind angle is 90° right. The aircraft under these conditions, will be blown to the left at an angle of 20° to the heading, that is the drift angle will be 20° left. Consequently the track will be 360° minus 20, or 340°. The ground speed will be 171 m.p.h.

39. MAIN ELECTRICAL SYSTEM

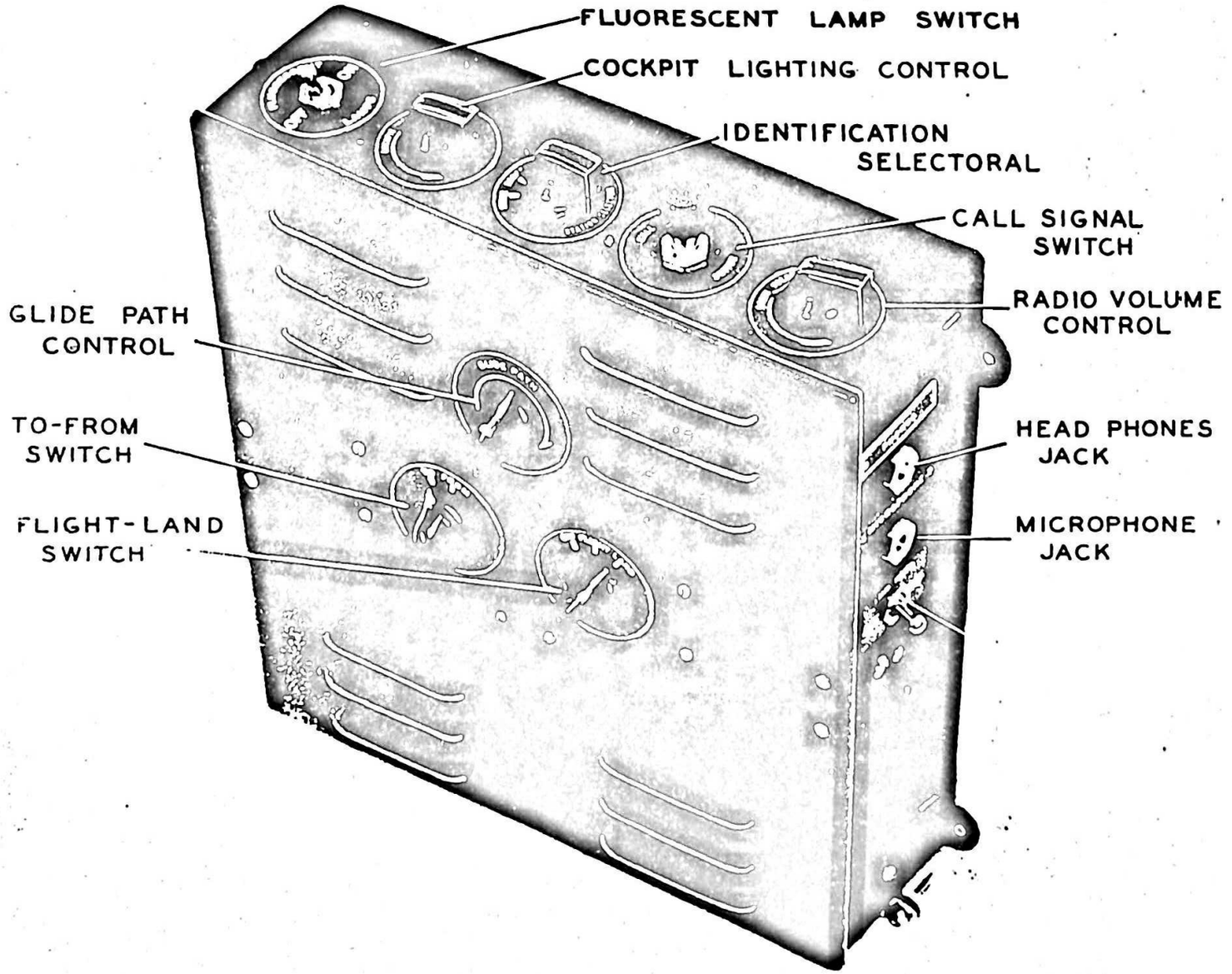
(a) Constant Voltage Transformer : Current for the operation of the Electrical mechanism in the trainer first enters the junction box in the base of the trainer, where it is switched to the constant voltage transformer. In trainers where the transformer is mounted away from the trainer the current is fed to the transformer first and then to the trainer base junction box.

(b) Power Distribution. From the constant voltage transformer current is distributed throughout the trainer through the following distribution points:

1. Base Junction Box.

(a) This unit serves as a terminus for the wiring of all electrical equipment in the base of the trainer and electrically connects the fuselage and desk.

.../(b)



15- Fuselage Control Box

(b) The base junction box also contains the following electrical units: (i) The Magnetic contactor for the turbine motor.
(ii) A step down transformer, supplying power to the teletorque motors.
(iii) A supply transformer, with dry disk rectifier and associated filter, for supplying the direct brake to the recorder motors.

2. Collector Ring Assembly

(a) This assembly is mounted on the bearing housing shaft assembly (spindle) and rotates with the trainer.

(b) It consists of 28 metallic discs (collector rings) with suitable insulation between each disc.

(c) Current is carried from the base junction box through the collector rings by means of 28 stationary contacts (brushes) to a circular row of 28 terminals at the top of the collector ring assembly and thence to the fuselage interconnector box.

3. Fuselage Interconnector Box

(a) This unit serves as a terminus for the various electrical circuits in the fuselage.

(b) Current is distributed through this terminus to the landing gear, propellor pitch and flap control device. (Not fitted to this trainer). Transmitters for the remote indicating instruments, the fuselage control box and the remote instrument junction box.

4. Fuselage Control Box

(a) The fuselage control box is mounted in the right hand side of the trainer cockpit and serves as a distribution point for current required for operation of electrical equipment on the instrument panel.

(b) It contains headphone and microphone jacks, together with the necessary controls and switches for operation of the radio and landing systems by the student in the trainer.

(c) With the fuselage control box are also located two fluorescent light current supply transformers and an additional transformer supplies current to the cockpit lights, compass deflector coils and the call Signal Switch. The compass deflector rectifier and adjustable resistor are also in the fuselage control box.

5. Remote Instrument Junction Box

(a) This junction box is located forward of the trainer instrument panel of the left side of the fuselage.

(b) It is electrically connected to the fuselage interconnector box and acts as a distribution point for current from the telegon instruments on the trainer instrument panel and the ventilating face in the nose of the trainer.

6. Desk Junction Box

This unit is mounted in the back of the instructor's desk and is the terminus for the various electrical circuits in the desk.

40. ELECTRIC FAN

An electric fan is provided in the nose of the Trainer for ventilating the cockpit. This fan is a standard unit, requiring only occasional oiling and the case ordinarily given such a unit.

.../41.

41. INSTRUMENT AND RECORDER LIGHTS

(a) Twelve-volt, 6 candle power, double bulbs are used for instrument lights. Current is obtained from the 110 volt - 12 volt transformer located in the control box in the Trainer Cockpit.

(b) Flourescent light is used to activate the luminous dials of the instruments. A power supply of 110 volts for each lamp is obtained from two transformers located in the fuselage control box. Bulbs for these lamps are the 4 watt size. The amount of light is governed by a shutter control located on the top of each lamp. Rotation of these unit controls the intensity of the light.

(c) There is also a control for daylight or ultraviolet light. By rotating the case of the unit, ultra-violet lighting is produced by a violet screen built into the case, while the daylight effect is obtained through a slot.

(d) The automatic recorder light uses two 25 volt. 0.2 ampere single contact bulbs. These bulbs are in series and obtain power from the 32 volt terminals (A) and (G) on the automatic recorder teletorque motor.

42. CONSTANT VOLTAGE TRANSFORMER

(a) This unit delivers a constant voltage irrespective of instantaneous or continuous variations in the live voltage.

(b) This is accomplished chiefly by a combination of a resonant electrical circuit and a high leakage resistance magnetic circuit.

(c) The resonant circuit stabilizes the voltage, while the magnetic circuit tends to prevent changes in the voltag

(d) A compensating winding is connected in series with the output and opposes small changes which appear in the output.

(e) Due to the fact that this regulating affect is obtained by means of magnetic relations between core and coil components, the unit has no moving parts and, therefore, nothing which requires adjustment or maintenance.

43. RADIO INSTRUMENT AND LANDING SYSTEMS

(a) RADIO: (i) Selection of Circuits: The radio equipment in the trainer provides for the selection of various circuits so that range, visual and aural markers, voice and landing marker signals may be reproduced to simulate those received in actual flight,

(ii) Method of Transmission: No actual radio transmission is employed. Instead all signal between desk and trainer pass over wired circuits. Microphones and earphones are provided at the instructor's desk and in the trainer, permitting two-way voice communication between instructor and student. Provision is also made at the instructor's desk for several additional pairs of earphones, so that other students may listen in while problems are being "flown" by a student in the trainer.

(b) INSTRUMENT LANDING SYSTEM: (i) The radio provides facilities for the selection of three types of simulated landing systems:

(a) The army Air Force system. (Army cross Pointer) using inner and outer landing trucks, automatic radio compass, visual and aural marker beacons and an Army cross pointer indicator.

(b) The Navy system (Navy cross pointer) consists of the Navy cross pointer instrument (landing) in conjunction with aural and visual landing markers.

(c) The British system (Standard Beam Approach) using the standard beam approach indicator with aural markers syncronised with the visual markers in the instrument.

(ii) The following radio equipment is provided in the fuselage for the student:

(a) A radio volume control for controlling the amplitude of the Radio Signals in the headphone.

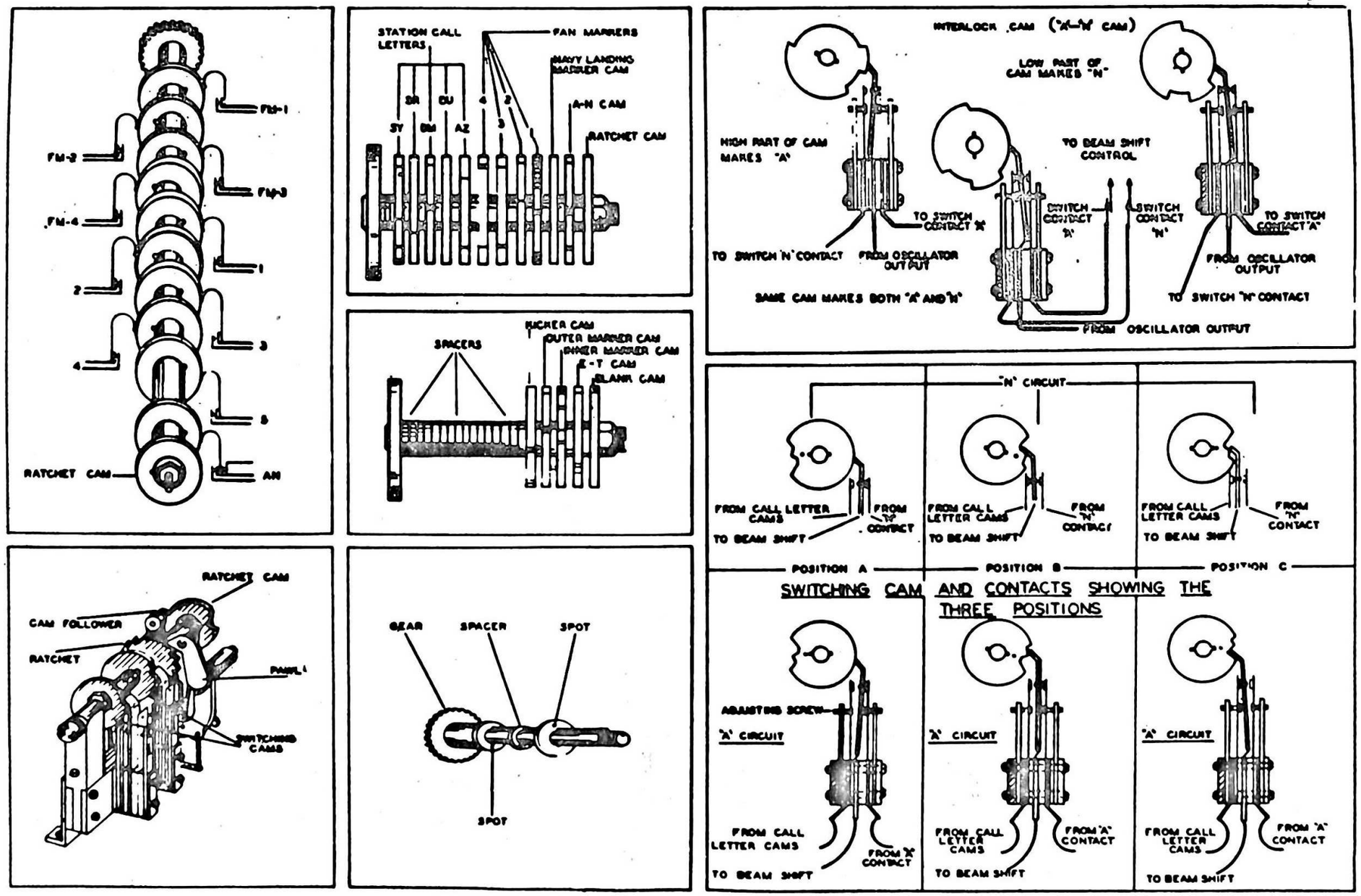


Fig. 16- Radio Range Keyer—Cams and Contacts

(b) A call switch for signalling to the instructor's desk.
(c) A station selector switch for selecting inner marker range or outer marker stations.
(d) "To-From" switch for reversing the cross pointer indication when leaving a station. In the "From" position this switch also closes a circuit which lights a lamp on the radio control chassis.
(e) In conjunction with this, and used with the Navy system is a selector switch which turns on the landing path needle of the cross pointer and remote landing path instrument when in the "Flight" position and lights an indicator lamp on the radio control chassis when in the "Land" position.
(f) A toggle switch is provided for turning on the standard beam approach indicator in the British System and the Army cross pointer in the Army system.
(g) A receptacle is provided in the front of the fuselage control box to receive one of three types of cable assemblies and instruments, determined by the landing system to be used. These cable assemblies are designed to automatically switch the electrical circuits of the trainer to suit the "individual" type of instrument being used.

(iii) When changing from one type of instrument landing system to another, the proper circuits at the desk are selected by a single switch marked "ARMY - NAVY - BRITISH". The circuits in the fuselage are automatically switched when the appropriate indicator and its cable are installed.

N O T E

While no serious damage will result if the switch at the desk is placed in other than its correct position for the type of indicator being used, such operation is not recommended and this fact should be impressed upon operating personnel.

4. In addition to the above, it is also necessary to change Keyer cam assemblies. The same cam assembly serves for Army and Navy landing systems and an additional cam assembly is provided to be installed when simulating the British system.

5. A selector switch is provided on the control chassis for selecting any one of the three systems.

Appendix 'A'

Summary of W.D.M. Components

1. The Four Racks. The wind drift mechanism utilizes four racks:

(a) The Wind Triangle Rack

Through the wind triangle rack the wind triangle pivot receives the wind drift movement and the wind triangle pinion receives the ground speed movement.

(b) The Ground Speed Rack

The rack is driven by a pinion which moves in proportion to the value of the changing ground speed of the Simulated aircraft. The rack determines the position of the coin roller which provides for an intermittent control of the recorder telechron drive motor.

(c) The Wind Speed Rack

The wind Speed rack is the agent by which the length of the wind speed vector is varied. Set in the wind bar, it is driven by a pinion, special provision being made for the wind bar to rotate without disturbing the setting of the work.

(d) The Air Speed Rack

This rack is driven by the air speed follow up motor and determines the value of the air speed side of the triangle.

2. The Four Differentials

In all, the wind drift mechanism utilizes four differentials. The following is a summary of their uses:

(a) Track Differential - The drives:

(i) Heading (from the heading of gear box).

(ii) Wind drift triangle pivot.

The Output : Track (Relayed to master teletorque)

(b) The Wind Drift Subtraction Differential - The drives:

(i) Ground speed plus drift (sliding and pivoting movement of main wind slide rack).

(ii) Wind Drift (wind Triangle pivot).

The Output : Ground Speed (Relayed to ground speed rack).

(c) Wind Speed Differential

The Drives :

1. Wind bar rotation.
2. Wind Speed control

The Output : Wind Speed (relayed through wind speed rack to wind speed crankpin).

(d) Relative Wind Angle Differential

The Drives :

1. Trailer heading (from heading gear box)
2. Wind direction control.

The Output : Relative position of heading to wind direction.

Appendix 'B'

AIR PUBLICATIONS AND R.A.F. FORMS

A.P. 1697A. Link Trainer Type D.D.2.
A.P. 1697B. " " " ANT 18.

A.P. 1697 Vol. I. Part I.
A.P.1697 Vol. II. Part I.
A.P. 1697A. & B. Vol.II. Part II.
A.P. 1697 Vol. III Part I.

(1) A.P. 2285A Vol.I.
(2) Kollsman Manual for Link Trainer Instruments } U.S.A.
(3) T.O. No. 08 - 25 - 8 Spare parts.

R.A.F. Forms

F. 1139 Log Books

F. 1451 Maintenance (Mortly)

A.M.O's.

A.M.O's. A.926/43.
A.990/45.
A.714/46.
N.269/46.
N.815/46.

References

(a) Miscellaneous Log Book (Form 1139) Instruction for use.
A.P. 1697A and/or B. Leaflet A. } Vol. II

(b) Servicing Form (Form 1451) Instruction for use.
A.P. 1697A and/or B. Leaflet A.2. } Part I.

(c) Link Trainer Maintenance.

A.P. 1697A Vol. II Part I. Leaflet A.8.
A.P. 1697B Vol. II Part I. Leaflet A.7.

(d) Period between complete overhaul.

A.P. 1697A Vol.II Part I. Leaflet A.9.
A.P. 1697B Vol.II Part I. Leaflet A.8.

LINK TRAINER LUBRICATION CHART

WARNING
EXCESS OIL WILL CAUSE DAMAGE

SECTION	HOURS	PART NAME	NO. PLACES	LOCATION	LUBRICANT	REFERENCE
FUSELAGE	AS NEEDED	ARTIFICIAL HORIZON DASH POTS	2	INSTRUMENT PANEL	CASTOR OIL	FIG. 73
	500	ARTIFICIAL HORIZON	6	INSTRUMENT PANEL	GUN OIL	FIG. 73
	50	CLIMB-DIVE VALVES ASSEMBLY	EXT	FUSELAGE FLOOR-LEFT SIDE CENTER	GUN OIL	FIG. 21
	50	STALL VALVE ASSEMBLY	EXT	FUSELAGE LEFT SIDE - FLOOR	GUN OIL	FIG. 19 & 80
	50	VENTILATOR FAN (FRONT)	2	FUSELAGE FRONT PANEL	GUN OIL	FIG. 2
	50	SPIN VALVE ASSEMBLY	1	FUSELAGE FLOOR-REAR	GUN OIL	FIG. 20
	50	CLIMB-DIVE COMPENSATOR SPRINGS	2	MOUNTED ON CLIMB-DIVE VALVES ASSEMBLY	GUN OIL	FIG. 21
	50	TORQUE SHAFT REAR BRACKET	1	MOUNTED ON FUSELAGE SEATBACK SUPPORT	LIGHT OIL	FIG. 18
	100	INTERCHANGEABLE STICK-WHEEL MECHANISM	12	FUSELAGE FLOOR - FRONT	LIGHT OIL	FIG. 26
	50	LEVERAGE SYSTEM	23	FUSELAGE FLOOR - CENTER	GUN OIL	FIG. 27
	50	PITCH ACTION SHAFT BRACKETS	2	FUSELAGE FLOOR - LEFT AND RIGHT	GUN OIL	FIG. 22
	AS NEEDED	SLIP-STREAM SIMULATORS (OLEO) INSIDE	3	FUSELAGE FLOOR - CENTER AND RIGHT	NO. 500 HOUDE	FIG. 8
	50	SLIP-STREAM SIMULATOR FITTINGS	12	FUSELAGE FLOOR - CENTER AND RIGHT	GUN OIL	FIG. 18, 21 & 76
	50	CONTROL WHEEL ECCENTRIC BUSHING, GEAR, BALL JOINTS	3	CONTROL WHEEL COLUMN (TOP AND BOTTOM)	GUN OIL	FIG. 76
	50	AILERON AND RUDDER VALVE COMPENSATOR SPRINGS	2	FUSELAGE FLOOR RIGHT SIDE AND REAR	GUN OIL	FIG. 18
	50	VIBRATOR MOTORS	2	REAR OF INSTR. PANEL AND TRANSMITTER PANEL	GUN OIL	FIG. 89
	50	ROUGH AIR SHAFT BEARINGS AND CRANK	3	FUSELAGE FLOOR - REAR	GUN OIL	FIG. 78
	50	STALL VALVE SLIDE HOLE - MUSH PIN - ARMS	3	STALL VALVE - TOP	GUN OIL	FIG. 80
	50	BELLOWS HOOK-UP SOCKETS	4	FUSELAGE FLOOR - LEFT, RIGHT, FRONT & REAR	MEDIUM GREASE	FIG. 4
	50	RUDDER PEDALS	6	FUSELAGE FLOOR - FRONT	MEDIUM OIL	FIG. 18
	50	RUDDER BAR	4	FUSELAGE FLOOR - CENTER - RIGHT	MEDIUM OIL	FIG. 18
	50	BANK TURNER SPIN-TRIP ASSEMBLY	9	FUSELAGE FLOOR - CENTER	MEDIUM OIL	FIG. 17
	50	LINKAGE - SPIN-TRIP - PITCH ACTION	EXT	FUSELAGE FLOOR - CENTER & RIGHT OCTAGON	MEDIUM OIL	FIG. 18
	50	ROUGH AIR GEARS	1	FUSELAGE FLOOR - REAR	MEDIUM GREASE	FIG. 78
	50	ROUGH AIR MOTOR	1	FUSELAGE FLOOR - REAR	GUN OIL	
	50	RUDDER VALVE	1	FUSELAGE FLOOR - RIGHT REAR	GUN OIL	FIG. 13
	50	ELEVATOR VALVE	1	FUSELAGE FLOOR - LEFT REAR	GUN OIL	FIG. 12
	50	AILERON VALVE	1	FUSELAGE SIDE - LEFT REAR	GUN OIL	FIG. 11
OCTAGON	50	MAIN UNIVERSAL JOINT	4	TRAINER OCTAGON - CENTER	HEAVY GREASE	FIG. 4
	50	BALL JOINTS - PITCH ACTION - BANK TURNER	2	TRAINER OCTAGON - CROSS	GUN OIL	FIG. 18
	50	TURNING MOTOR GEARS	2	TURNING MOTOR ASSEMBLY	HEAVY GREASE	FIG. 7
	50	TURNING MOTOR SLIDE VALVES	10	TURNING MOTOR BELLOWS BANK	POWDERED GRAPHITE	FIG. 77
	SEALED	TURNING MOTOR BALL BEARINGS		TURNING MOTOR ASSEMBLY	SEALED	
	50	BELT TIGHTENER ASSEMBLY	2	TRAINER OCTAGON ARMS - FRONT	GUN OIL	FIG. 9
BASE	100	TURBINE AND MOTOR UNIT	2	TRAINER BASE - BOTTOM	LUBRICO M6	FIG. 3 & 90
	100	TRANSFER ELBOW	1	TRAINER BASE - BOTTOM OF COLLECTOR RING	MEDIUM GREASE	FIG. 3
	SEALED	MAIN HOUSING BALL BEARINGS		TRAINER BASE - ON CROSS	SEALED	
EMPENNAGE	100	RUDDER AND CONTROLS	4	FUSELAGE EMPENNAGE - REAR	LIGHT OIL	
	100	ELEVATOR AND CONTROLS	5	FUSELAGE EMPENNAGE - REAR	LIGHT OIL	
WINGS	100	AILERON HINGES	4	LEFT AND RIGHT WINGS - TOP	GUN OIL	
DESK	50	AUTOMATIC RECORDER DRIVE GEARS	4	AUTOMATIC RECORDER UNIT - DESK	LIGHT OIL	FIG. 45
	50	RADIO RANGE KEYER	10	RADIO DESK DRAWER	GUN OIL	FIG. 62
	50	VIBRATOR MOTOR	2	REMOTE INSTRUMENT CASE PANEL	GUN OIL	FIG. 28

*Applicable to Trainers, Link Serial Nos. 4395 to 5550, inclusive

Fig. 17. Lubrication Chart

ELECTRICAL & INSTRUMENT SECTION

HENLOW DIVISION, R.A.F. TECHNICAL COLLEGE

GENERAL AND ELECTRICAL INSTRUMENTS

Instrument Precis No.7

1. PRESSURE GAUGES

These are generally operated on the Bourdon Tube principle. Any increase of pressure above that of the atmosphere tends to make the oval cross-section circular, thus straightening the tube, and causing movement of its free end. This movement is conveyed by a link and quadrant to the pointer spindle. A guarded hairspring takes up backlash, and stops are fitted to prevent the tube being strained beyond its elastic limit.

The Bourdon tube is sometimes replaced by a weak capsule in low range instruments, e.g. Suction and fuel pressure gauges. Types in service use are:-

(a) Direct type - where liquid or gas under pressure is admitted to the bourdon tube direct. (Ref. A.P.1275A. Vol.1. Sect.3. Chap.4).

(b) Transmitting type - where the liquid or gas under pressure is admitted by a hollow bolt to a brass fitting which contains a light corrugated capsule. This capsule itself is connected to the B.T. by means of a very small bore tube (capillary tube).

The B.T., capillary and capsule are completely filled with a suitable liquid of low viscosity and freezing point (e.g. ethyl Alcohol) and sealed, all air being excluded.

Any pressure being exerted on the capsule will be transmitted by the liquid to the B.T. causing the B.T. to move and to indicate the applied pressure.
(Ref. A.P.1275A. Vol.1. Sect.3. Chap.19).

(c) Direct type gauge using a pressure transmitter
This system uses a directed type pressure gauge; ordinary small bore tubing, and a pressure transmitter. Its action being the same as for the transmitting capillary type.

The transmitter is a rubber disphragm which when acted upon by an external pressure, transmits the pressure along the pipe line to the B.T. in the indicator. Incorporated in the transmitter is a disc which when filling is moved to contralise the rubber diaphragm, and returned back to its original position after filling.
(Ref. A.P.1275A. Vol.1. Sect.3. Chap.9).

(d) Calibration Adjustments. In most instruments the movement of the controlling member is so magnified that an approximately even scale results. The rangeof the pointer is determined by the lever ratio, and the calibration of the dial by the Angular movement between levers and links.

(e) Instrument Errors (see Fig.4)

(i) Ranging error is due to incorrect lever ratios and can be detected on check calibration by a regular increasing or decreasing error, i.e. each scale interval is equally magnified.

(ii) Calibration error is due to incorrect angular movement, and shows as an error which varies for each scale interval. Connected by altering lever angles by trial and error.

(iii) Pointer error is bad positioning of pointer which gives a false reading by an equal amount on each reading.

(iv) "Bad Spot" error is an error which occurs in one part of the scale only, and is due to a faulty controlling member, and can only be corrected by replacing the controlling member.

(v) An erratic error is usually caused by dirt or friction, in which case the mechanism needs cleaning.

(f) Calibration of Pressure Gauges. Pressure gauges are calibrated by using a Dead weight tester and applying known pressures by means of weights to gauge under test. (Ref. A.P.1275A. Vol.1. Sect.6. Chap.3).

2. MEASUREMENT OF HEIGHT (Ref. A.P.1275B. Vol.1. Sect.2. Chap.1).

The earths atmosphere is a relatively thin layer of gases (approx. 80% nitrogen, 20% oxygen) which surrounds the earth and revolves with it; becoming more and more diffused with increasing distance from the earths surface. The approximate depth of this layer is 50 miles, and besides the gases a certain amount of water vapour is present.

The gases above the earths surface have weight and therefore will exert a force on the earths surface, approximately 14.7 P.S.I.; this figure however, varies from day to day and also with location.

It can, therefore, be seen that if we ascend, the weight of air above us decreases, and using this change in weight we can determine height above the earths surface, or above sea level. For measurement of barometric pressures on the earths surface we use a barometer.

(a) Barometers

If a glass tube above 36 inches long and sealed at one end is completely filled with mercury and inverted in a bowl of mercury without allowing any air to enter, only a little mercury in the tube will run into the bowl, i.e. the mercury column will drop a few inches and then remain stationary. This is because the pressure of the atmosphere acting on the surface of the mercury in the bowl is sufficiently great to support the mercury in the tube. If the pressure were to fall, the level of the mercury in the tube would also fall, and vice versa.

This simple piece of apparatus if erected and left alone, will indicate at any time the pressure of the atmosphere in terms of the height of the mercury column.

Thus we have a very simple barometer. Modern mercury barometers operate on exactly the same principle, but there have been various technical refinements. It is usual to have a scale graduated in inches, millibars or millimeters placed alongside the column of mercury together with a thermometer and a vernier device to assist in obtaining an accurate reading.

As has been pointed out, the pressure will usually vary from day to day, and from place to place, so that there is no fixed atmospheric pressure for all points on the earths surface. In order, however, that some standard of comparison may exist for calibration purposes, an indicated height of 29.994 inches

.../of mercury

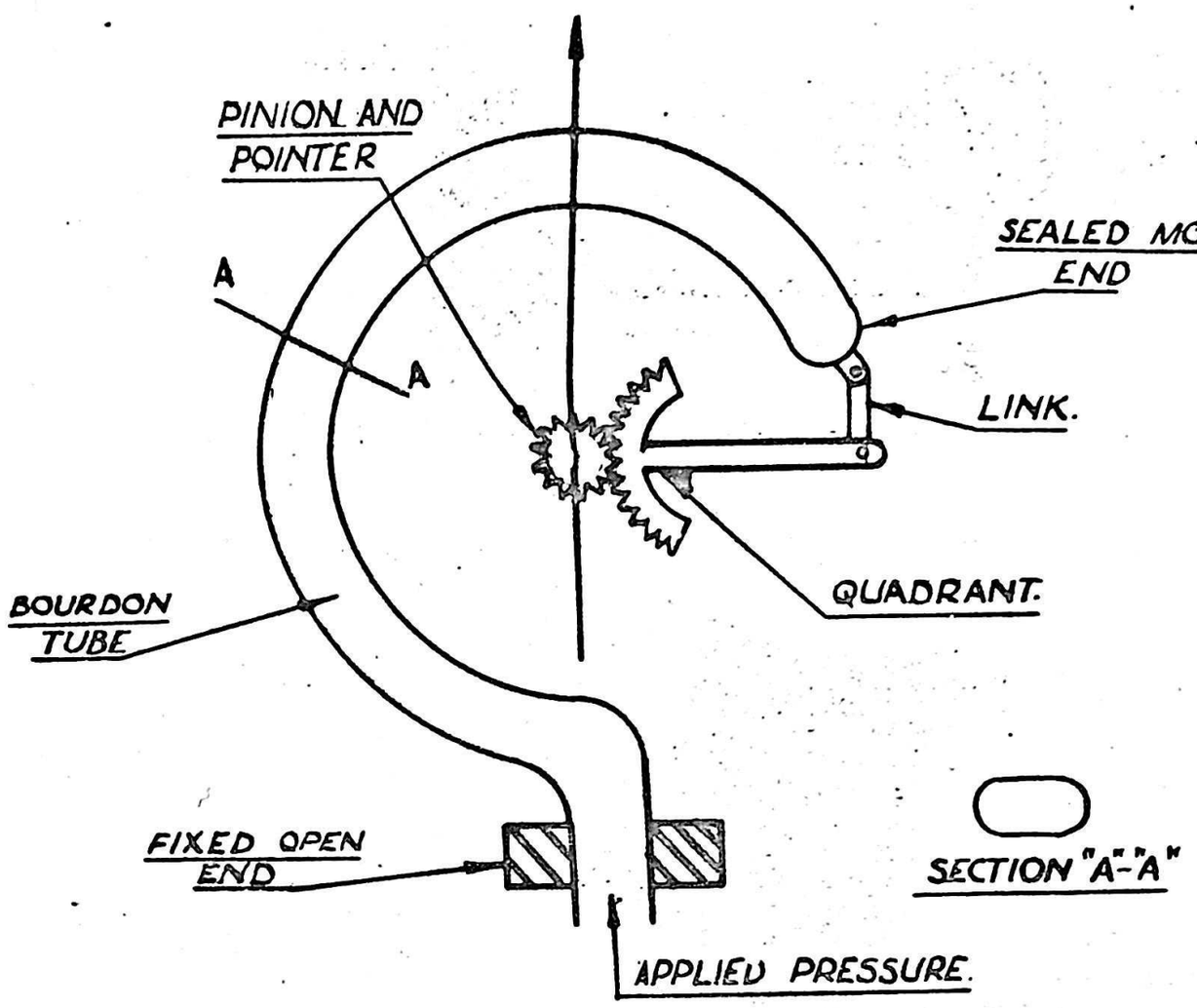


FIG 1 – SIMPLE BOURDON TUBE.

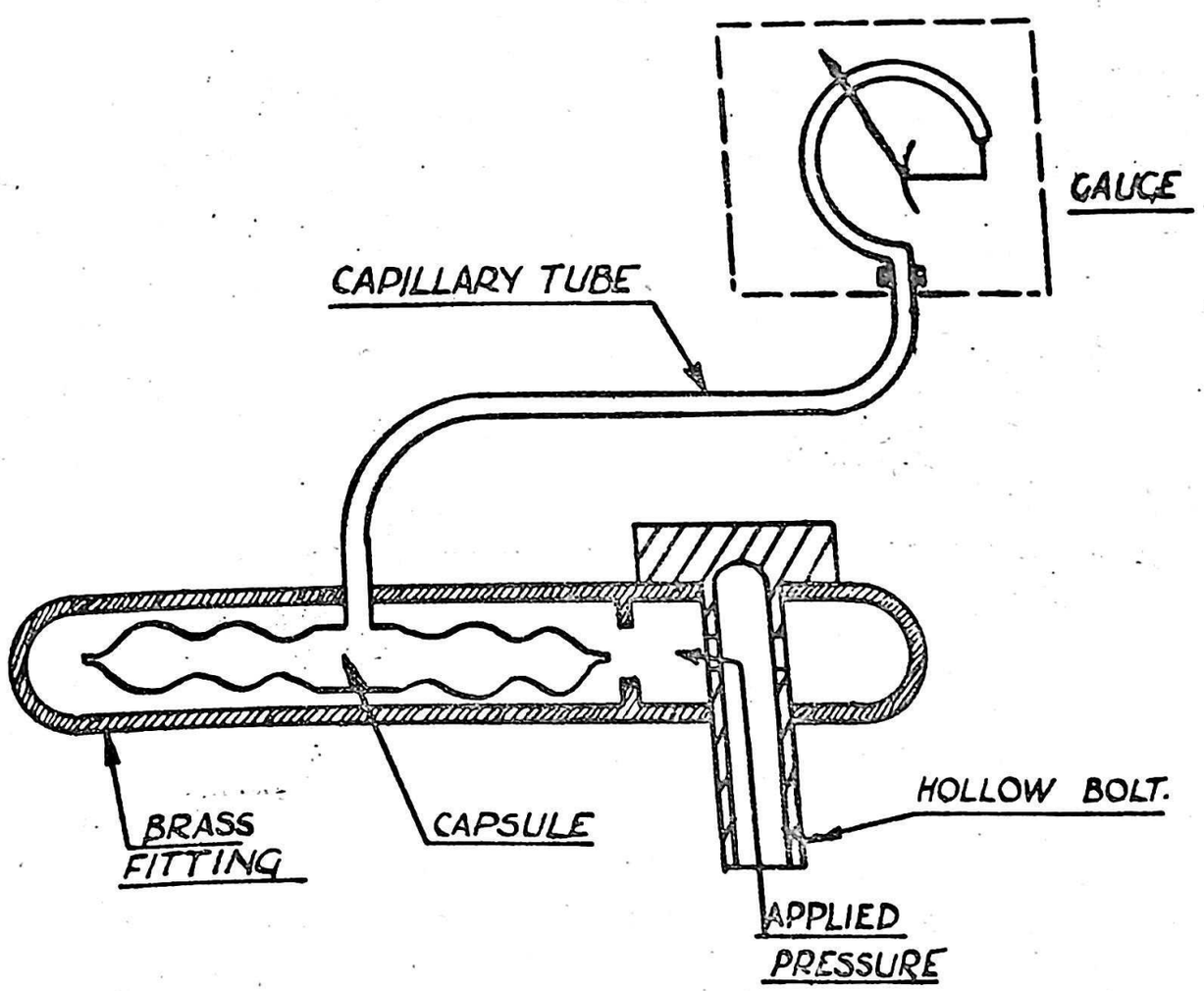


FIG 2 – TRANSMITTING TYPE PRESSURE GAUGE

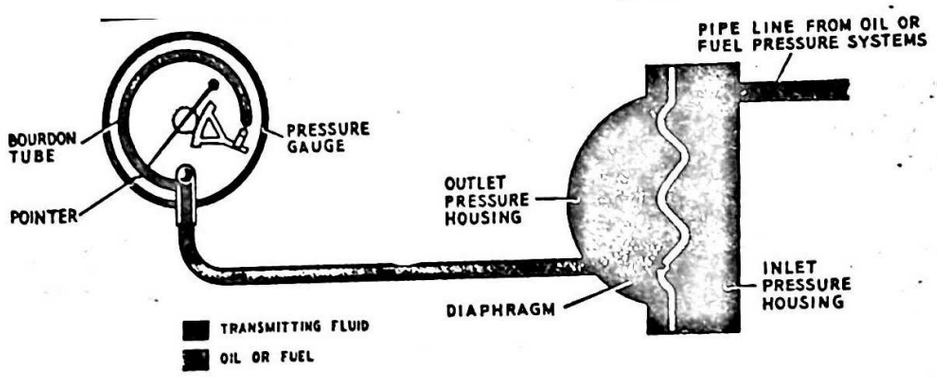
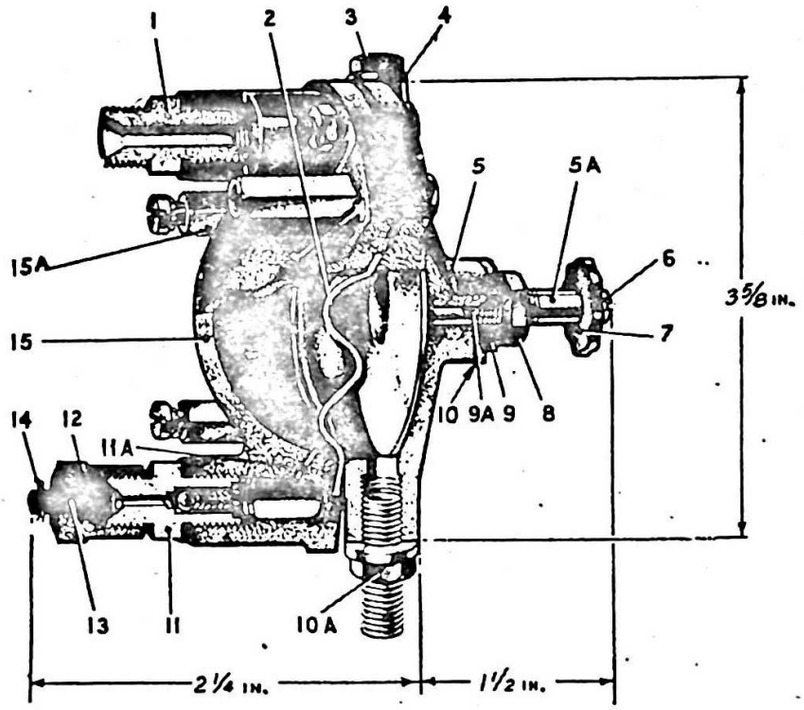
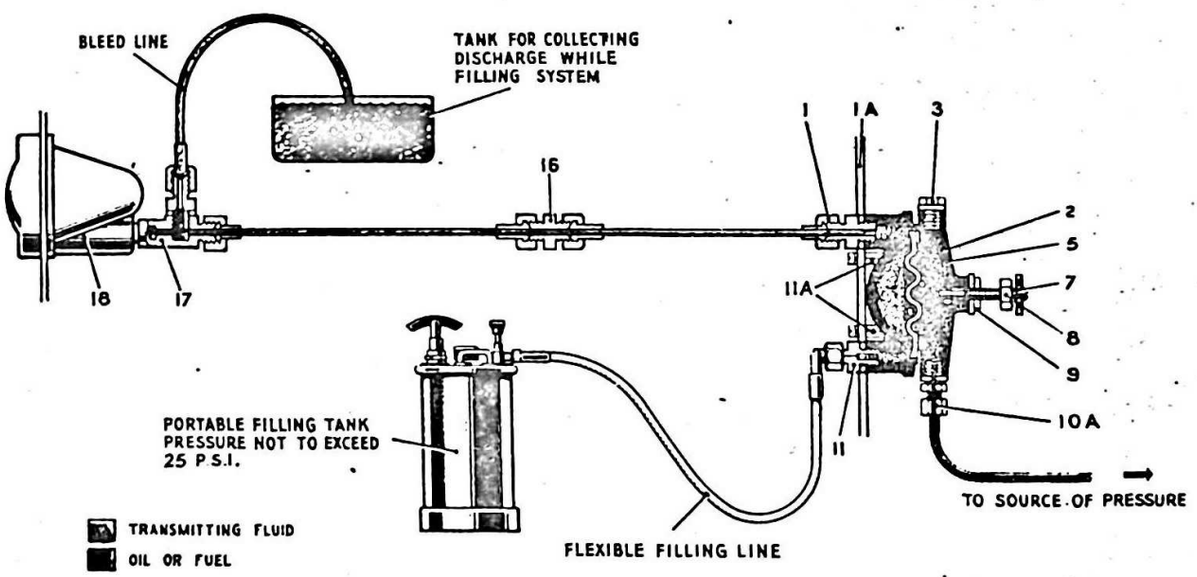


Fig. 3a Pressure transmitter, principle of operation



1. Union, pressure outlet
2. Diaphragm
3. Plug, blanking
4. Washer
5. Housing, inlet pressure
5A Shaft, centralising disc assembly
6 Retaining screw
7. Knob, centralising disc assembly
8. Locking nut
9 Washer
9A Dowel
10. Sealing washer
10A Union, pressure inlet
11. Non-return filler valve assembly
11A. Port
12. Cover, non-return filler valve
13. Plug
14. Split pin
15. Pressure outlet housing
15A. Spacers, mounting

Fig. 3b–Pressure transmitter, general arrangement of mechanism



1. Union, capillary tubing
1A. Bulkhead
2. Diaphragm flexible
3. Plug, blanking
5. Housing, pressure inlet
7. Knob centralising disc assembly
8. Lock-nut
9. Washer
10A. Union oil or fuel inlet
11. Filler valve assembly
11A. Spacers
16. Union, double ended
17. Bleed valve assembly
18. Pressure gauge

Fig. 3c–Filling device connected to pressure transmitter

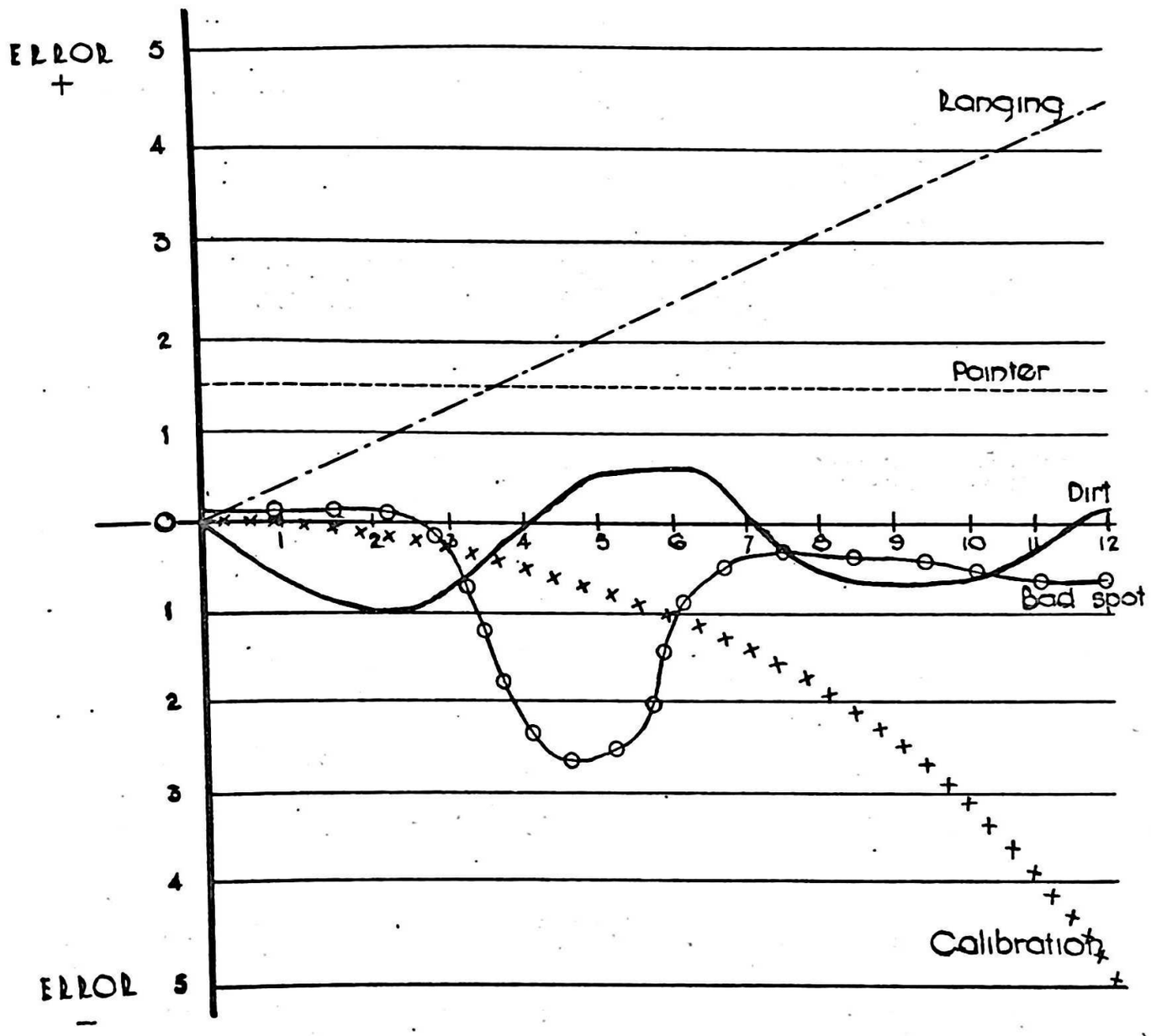


FIG 4 - GRAPHICAL ANALYSIS OF ERRORS

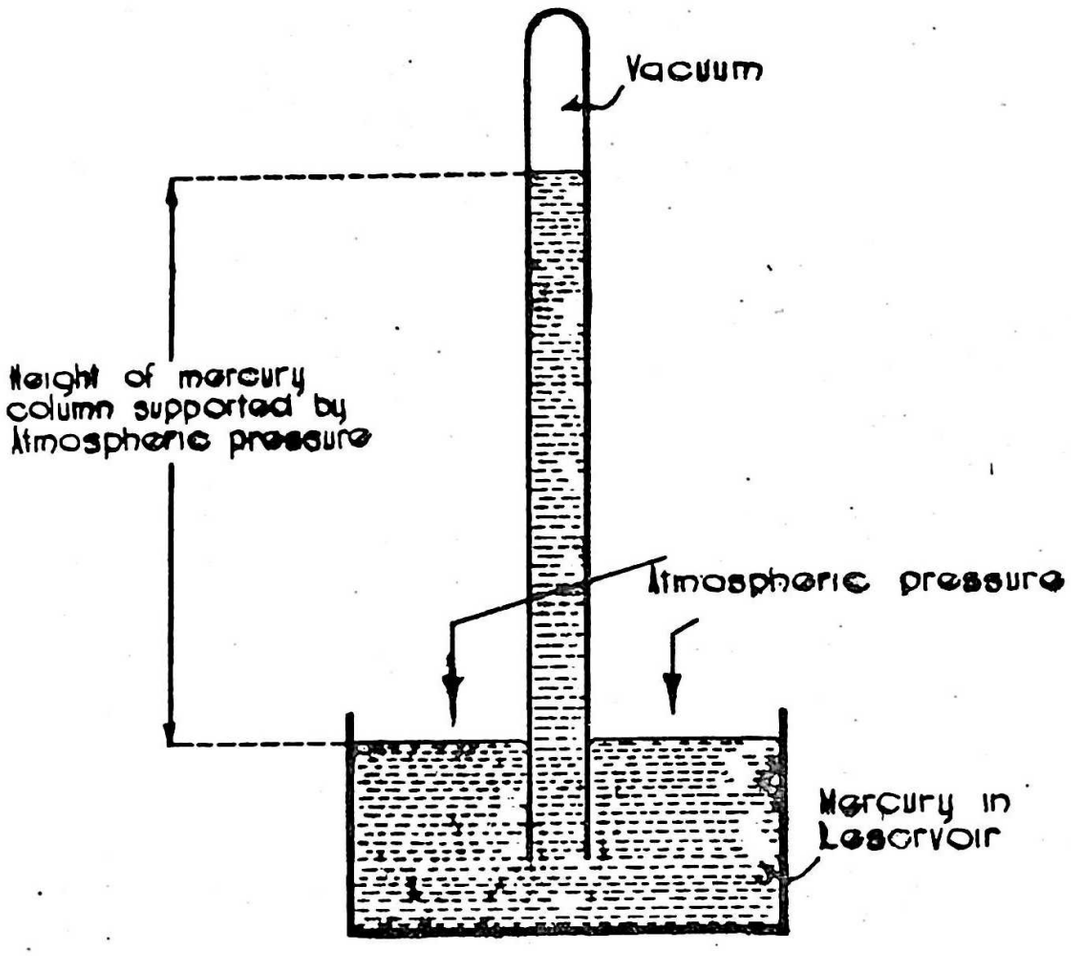


FIG 5 - SIMPLE BAROMETER

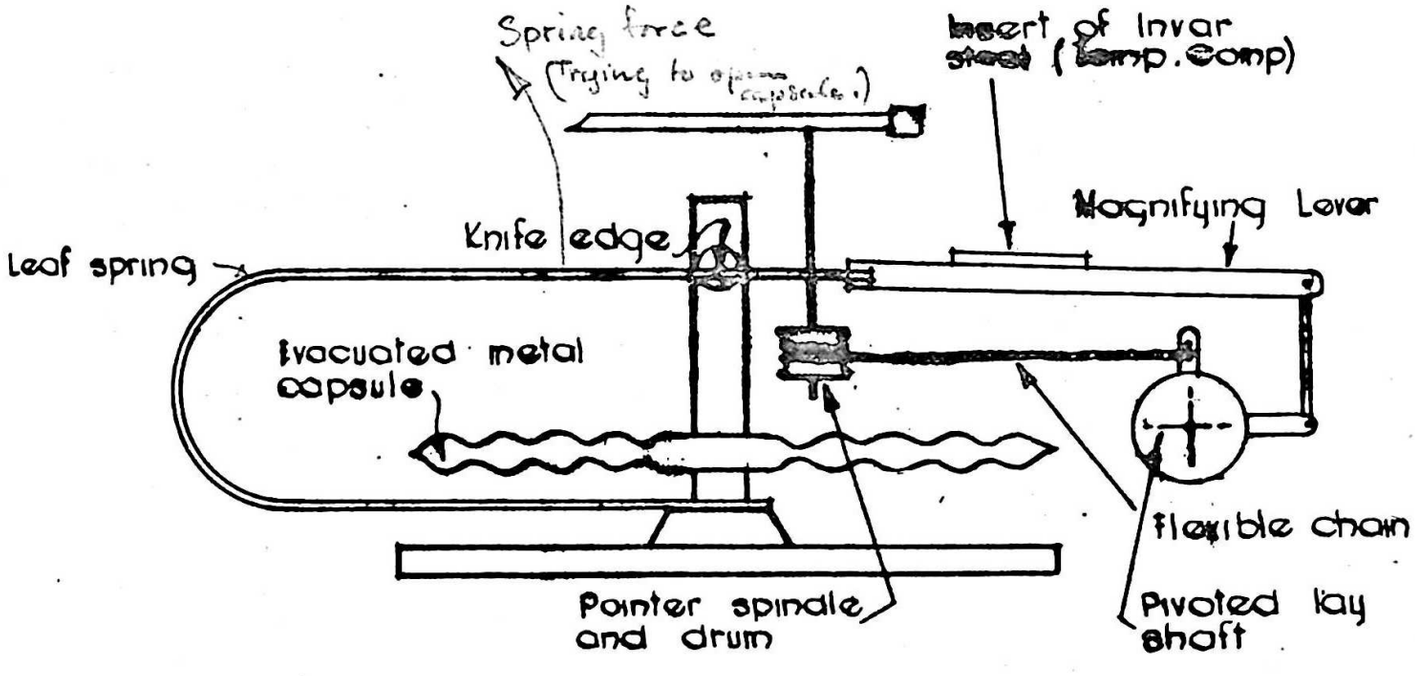


FIG 6 - ANEROID BAROMETER

of mercury is taken as the average atmospheric pressure at mean sea level at 51½° Latitude (N. or S.) and temperature at 16.67°C. This is known as "London Laboratory Condition", and is the standard used in the calibration of most barometers used by the instrument trades in the R.A.F.

However, another set of conditions is used as a standard by physicists and chemists, giving an indicated height of 29.921 inches (760 mm) of mercury at 45° Latitude and temperature 0°C. These latter conditions are known as "Standard Conditions". Both of these conditions bear a fixed relation to the overall standard unit of atmospheric pressure, the BAR (equal to 10^6 dynes per sq.cm., the millibar is the unit commonly employed, standard being 1013.2 m.b.).

(b) Service type Barometers

(i) Fortin, used only to obtain barometric pressures. It has an adjustable reservoir by which the level of mercury in the reservoir is brought to the fiducial point before a reading is taken. It can be measured correct to 0.002".

(ii) The Standard Barometer is a "Kew" barometer designed for use on units as a standard test barometer. It has two scales in thousands of feet and another in contracted inches, and is calibrated under London Lab. conditions. (The two height scales are for I.C.A.N. and isothermal calibration).

(c) Altimeter Calibration Laws

It has been stated that the atmospheric pressure changes with height, the pressure becoming less as height increases. In order to calibrate an altimeter to read height, the relationship between pressure and altitude must be known. The atmospheric pressure at any particular height is variable, and therefore, it is not possible to state what pressure corresponds to a given height, without taking direct measurements of the various factors at and up to that height. These factors are, pressure on ground and pressure at height in question, and the temperature at all heights between these two levels.

For assessing height two laws are in use, known as the Isothermal and the I.C.A.N. laws, the latter being more widely used. Neither of these laws is entirely accurate but the I.C.A.N. law is much more accurate as an average than the Isothermal. It is possible to apply temperature corrections to either law to give a more accurate height, if the measured temperature at the particular height is very different from that according to the laws. Correction is made by using a computor.

(i) Isothermal Law - based on the assumption that the temperature at all heights is 10°C.

(ii) I.C.A.N. Law - assumes a constant temperature fall of 1.98°C per 1,000 ft. from 15°C on the ground, to -56.5°C at 36,000 feet, above which it remains constant.

.../(d)

(d) Altimeters

It can be seen that it is impossible to use a mercury barometer to measure height in an aircraft. We therefore use an aneroid barometer, suitably adapted to measure and indicate height.

It uses an evacuated metal capsule, corrugated for strength but which will collapse when acted on by the atmospheric pressure. To prevent total collapse a leaf spring is used to distend the capsule to its normal shape under normal atmospheric pressure. It can be seen that the spring tension will oppose the atmospheric pressure acting on the capsule, and if the pressure varies, the spring tension being constant, the capsule will open or close slightly. This movement of the leaf spring is small but is magnified by a lever, and through a link and lay shaft, the movement is transferred to the pointer by means of a fine meshed chain. (See fig.6).

For ambient temperature compensation a piece of invar steel is fitted to the magnifying lever and corrects for temperature changes of the leaf spring.

(e) Service Types

All service types are similar to the aneroid barometer, and differ only in construction and range over which they may be used.

(i) Sensitive (Mk.14) (Ref. A.P.1275B. Vol.1. Sect.2. Chap.4).
Designed to record very small changes in pressure and hence very small changes in altitude. Readings may be taken to within 10 feet, and working range may be 0 to 35,000 ft or 50,000 ft.

It has a subsidiary scale marked in millibars and a setting knob, by which, settings can be made to the mechanism to correct for change of atmospheric pressure on the ground during flight, and also for correcting the altimeter for landing at an airfield which is at a different height from that at which the aircraft departed.

Instead of having only one capsule, this type may have two or more stacked together. This in most case gives the capsules sufficient inherent strength to withstand atmospheric pressure without the use of a leaf spring. Such movements require a minimum amount of temperature compensation.

The magnifying mechanism is still similar as before, still using the basic principle of the lay shaft, a quadrant and pinion, and in the case of these sensitive altimeters, using a clock mechanism to operate three pointers, one giving one revolution of the dial for 1,000 ft. a second one dial revolution for 10,000 ft. a third again geared at 10:1.

The case housing the mechanism is airtight but is connected by means of a pipe line to a static vent or the static side of the pressure head so that true static pressure is measured.

.../(ii)

(ii) Standard types, Mk.16 & 17

Again similar to previous types but have only a single pointer, and therefore not so accurate in their indications; operation is similar and again they all have an airtight case and are connected to the static pipeline.
(Ref. A.P.1275B. Vol.1. Sect.2. Chaps. 5 & 6).

(f) Calibration of Altimeters
(Ref. A.P.1275B - see Appendix for type to be tested)

For test purposes we use a master or Vacuum Indicator. It consists of a mercury 'U' tube fitted with two cocks so that suction and pressure supplies may be varied, and also the scale is graduated in thousands of feet, pound per square inch, and inches of mercury. It is a multi purpose standard. For the purpose of calibrating altimeters the vacuum indicator is connected to the test chamber (see Fig.7), and the chamber to its control box to which is taken the pressure and suction supplies.

Before the vacuum indicator can be used it has to be correctly set up. It will be seen that it has two scales, a long one having several graduations against which readings are taken, and a small one which is used to set up the large one to allow connection for atmospheric pressure. Each mercury column supports two steel balls, these aid the taking of a reading and also help to keep the tube clean.

(i) Setting up of Vacuum Indicator

(a) Level indicator using levels:

(b) Move the zero of the main scale to coincide with the level of the mercury. Lock scale.

(c) Slacken subsidiary scale and adjust to 1013.2mb against main scale zero.

(d) Obtain barometric pressure of the day and set main scale zero to this pressure on subsidiary scale.

Vacuum indicator is now ready to use.

(ii) Test of Altimeters

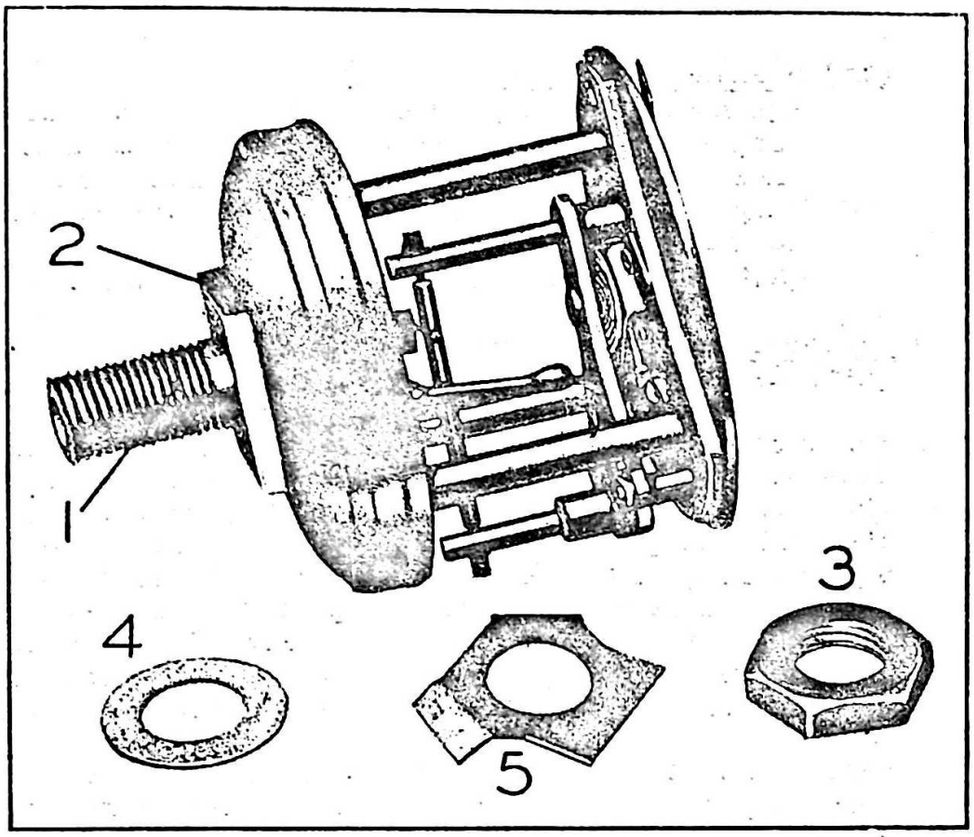
Two tests are generally carried out, a leak test and a ranging test. These are given fully in the appropriate Appendix but note should be taken that rate of ascent and descent is laid down. If these rates are exceeded appreciably lag may be noticed. Light tapping or vibration is permissible during tests.

3. BOOST GAUGES

These instruments are used to indicate the pressure in the induction system of an engine. The dial is calibrated in P.S.I. positive and negative about zero, or normal atmospheric pressure. As the pressure indicated is above, or below atmospheric pressure, the 'at rest' indication given by the gauge may vary from day to day due to varying atmospheric pressure. This must be taken into account when testing these instruments.

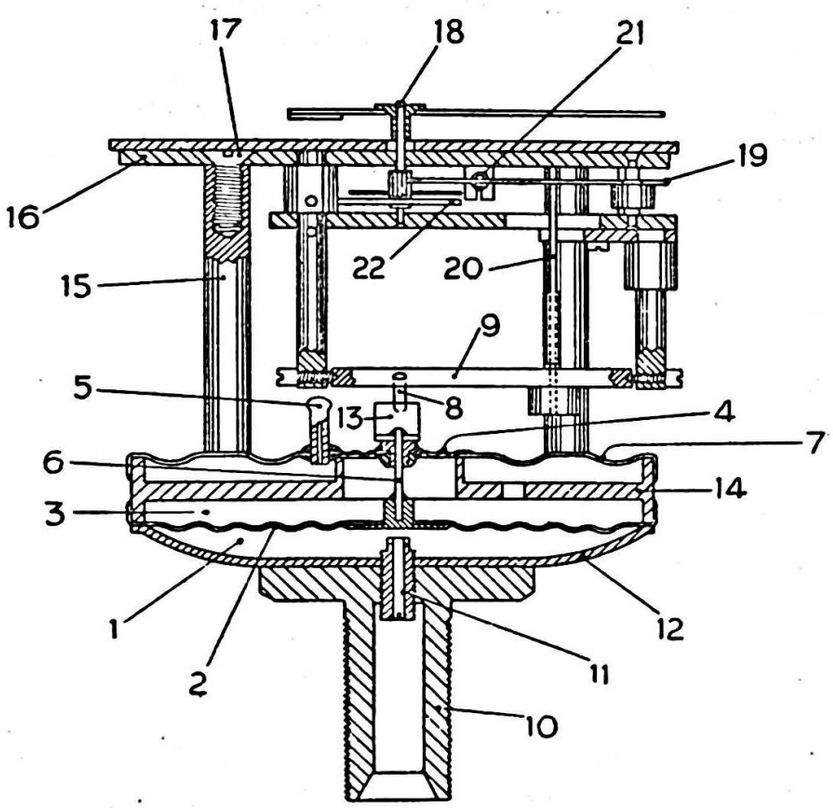
The general construction consists of an evacuated capsule in an airtight case which operates a pointer through a linkage, quadrant and pinion. The later types of instruments do not require an air tight case

.../as the



1. ¼ in. B.S.P. thread
2. Square boss
3. Nut
4. Sealing washer
5. Locking plate

Fig. 7 —Mechanism of boost gauge, Mk. IIIC*



1. Pressure chamber
2. Operating diaphragm
3. Sealed chamber
4. Conveyor diaphragm
5. Sealing tube
6. Connecting rod
7. Compensating diaphragm
8. Horizontal ranging lever
9. Layshaft
10. Union
11. Choke
12. Bottom plate
13. Angle piece
14. Intermediate plate
15. Supporting pillar
16. Top plate
17. Countersunk screw
18. Pinion
19. Sector
20. Vertical ranging bar
21. Sector stop
22. Hairspring

Fig. 8 –Sectional view of boost gauge, Mk. IIIC*

as the construction has been designed to prevent errors due to leaks. There are several different types of construction and these are due to manufacturing rights, the dial and requirements however are the same for all.

(a) Compensated type (See Fig.8)

Pressure Acts in a chamber on a diaphragm (Main) on the other side of which is a fixed pressure, and the main diaphragm is connected to a conveyor diaphragm by means of a push-pull rod. These two diaphragm form a capsule. From the conveyor diaphragm a link takes the movement via a layshaft and quadrant to the pointer.

As atmospheric pressure varies with altitude, this change of pressure acting on the conveyor diaphragm tends to lift by itself, and will operate to give a false reading. Therefore, we have to compensate for altitude acting on the conveyor diaphragm, and this is done by using a third diaphragm (Compensating diaphragm) and arranging that the mechanism is mounted on it. Therefore, with a change in pressure with altitude we get the same movement on the compensating diaphragm that we have on the conveyor diaphragm, but no resultant movement of the pointer.

(b) Calibration of Boost Gauges
(Ref. A.P.1275A. Vol.1. Sect.3. Chap.6 Appendix I)

A Vacuum Indicator or special calibrator may be used for test purposes. Full details of use are given in the above appendix.

4. AIRSPEED INDICATORS AND ACCESSORIES (Ref. A.P.1275B. Vol.1. Sect.1.Chap.1)

An Airspeed Indicator is a sensitive differential pressure gauge, measuring the pressure difference of the still air surrounding the aircraft against the pressure of the air built up by the forward motion of the aircraft. In general terms the pressure built up is proportional to the square of the airspeed.

Airspeed Indicators now issued to the Service are calibrated to the law

$$P = \frac{1}{2} \cdot \rho_o V_i^2 \left\{ 1 + \frac{V_i^2}{4a_o^2} \right\}$$

where V_i is indicated airspeed.

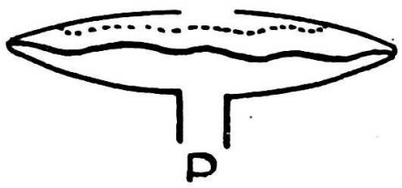
ρ_o is standard sea level density of air

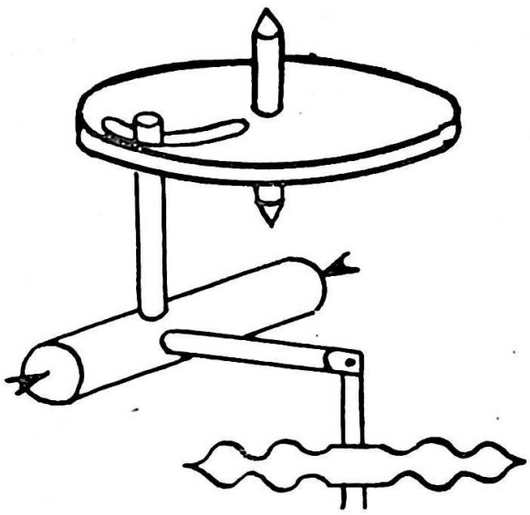
a_o is standard sea level velocity of sound

(a) Construction. There are various types in use in the service having different constructional details. The instrument mechanism is contained in an airtight case having two connections, one to allow still air into the case, the other allowing the pressure built up by the forward speed of the aircraft into a capsule. The pointer indicates the difference between these two pressures. The scale of the instrument is fairly evenly divided, but to obtain this the construction is so designed to remove the effect of the square law. This is done by progressively decreasing the movement of the controlling member by incorporated a lever whose operating length increases as the capsule expands. Two examples are (a) an upright, working in a slotted quadrant tail, and (b) a banana shaped slot in the quadrant gear wheel. In the "oyster" shaped type the diaphragm is covered by a mathematically curved brass casing which progressively limits the effective area of the diaphragm thereby making it stronger.

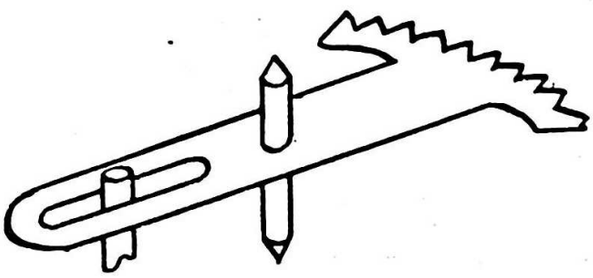
In all mechanisms a positive stop is fitted.

A. OYSTER TYPE.





B. SLOTTED GEAR TYPE



C. SLOTTED QUADRANT

FIG. 9. – AIRSPEED INDICATOR (COMPENSATING MECHANISMS)

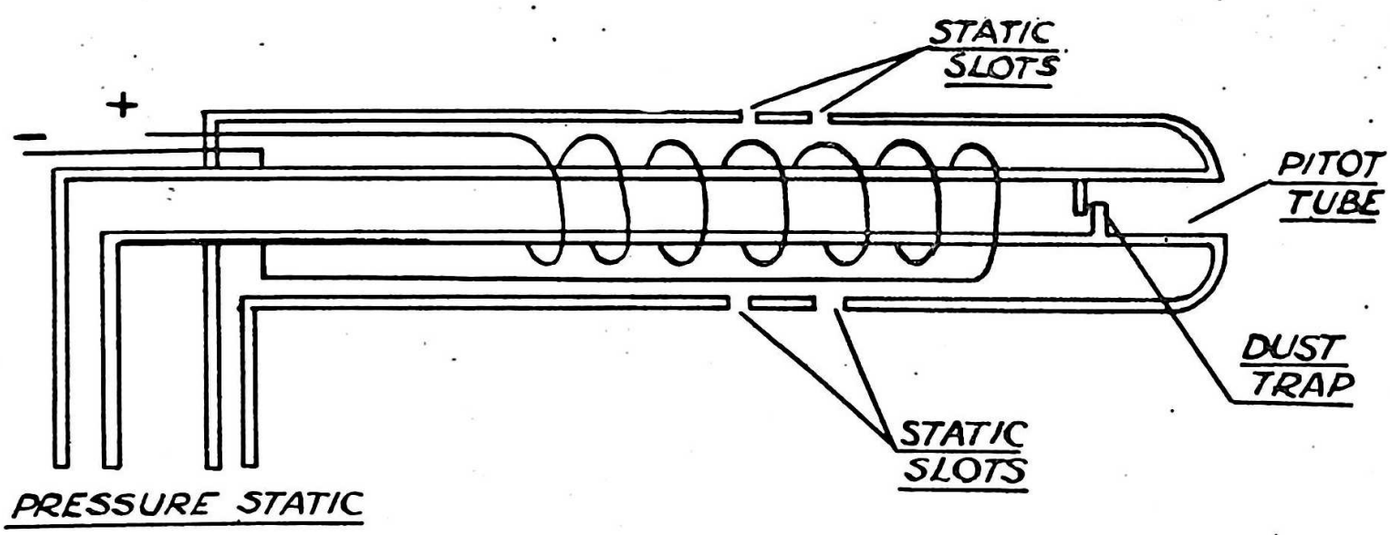
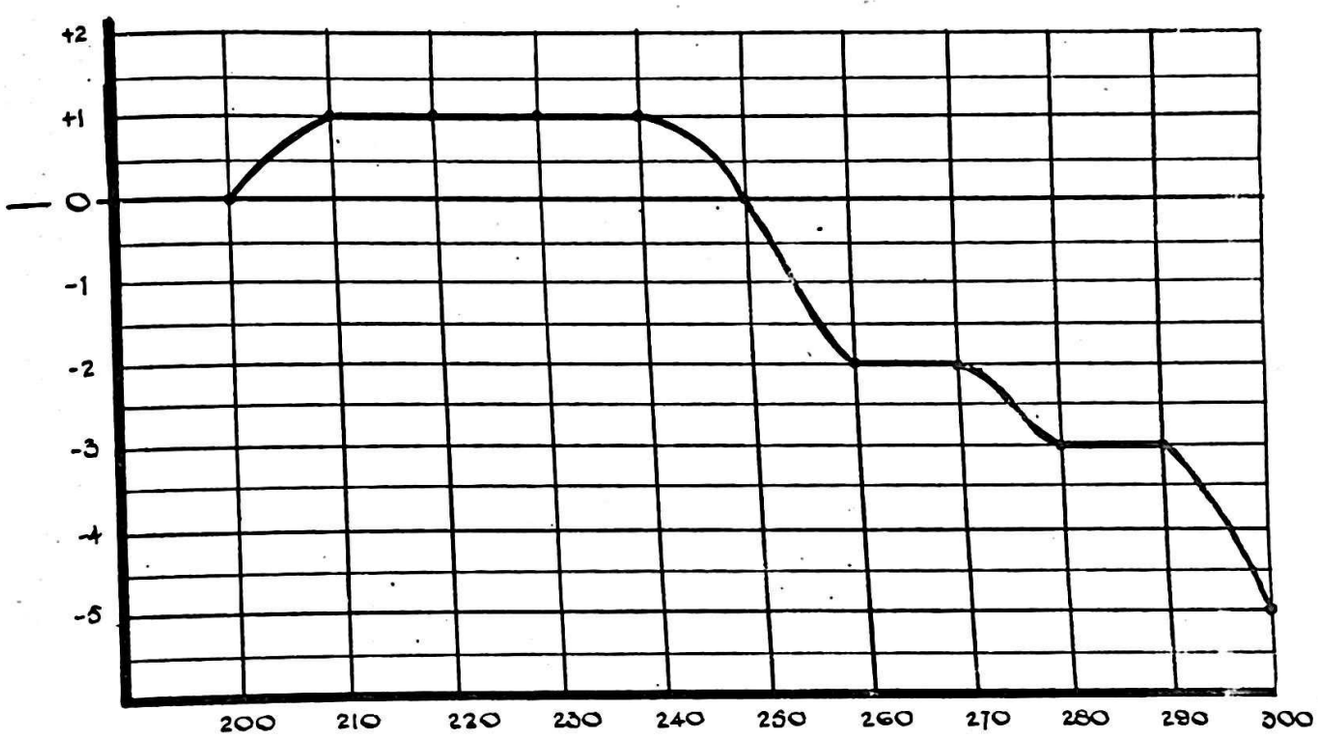


FIG. 10. PRESSURE HEAD (ELECTRICALLY HEATED)

A.

Calibrator Reading	I.A.S.	Instrument Error Correction	Position Error Correction	Total Correction to I.A.S
200	202	-2	+2	0
210	211	-1	+2	+1
220	221	-1	+2	+1
230	230	0	+1	+1
240	240	0	+1	+1
250	250	0	0	0
260	260	0	-2	-2
270	269	+1	-3	-2
280	279	+1	-4	-3
290	288	+2	-5	-3
300	298	+3	-7	-5

B.



GRAPH OF TOTAL CORRECTIONS.

C.

R.A.F. FORM 1167

Indicated Air Speed	Correction to obtain rectified Air Speed.
203	
248	+1
252	0
257	-1
275	-2
294	-3
299	-4
301	-5

FIG 11 - PREPARATION OF AIRSPEED ERROR CARD.

(b) Airspeed Indicator Errors

(i) Instrument Error - found by calibration.

(ii) Position Error - The A.S.I. is operated by a pressure head, and since it is impossible to fit the pressure head where it is entirely free from distorted air-flow, it is therefore fitted where the distortion is least, and a table given the amount of error at various speeds can be found in the Pilots Notes Manual for the type of aircraft.

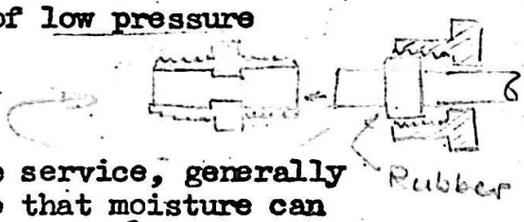
(iii) Compressibility Error - The compressibility of the air is allowed for on the calibrator.

(iv) Density Error - A.S.Is. are calibrated at ground density. Since density decreases with increasing height, true air speed is determined from corrected Air Speed by using a Height and Air Speed Computor.

Corrections for errors (i) and (ii) are given by an error card, which gives corrected airspeeds. Details regarding the preparation of corrector card is given in A.P.1275B. Vol.1. Sect.1. Chap.1. Para. 43 to 46 incl.

(c) Accessories

(i) Connections are made by means of low pressure unions and aluminium tubing.



(ii) Pressure Heads

Several types are in use in the service, generally they are electrically heated so that moisture can be dispersed. They may have one or tow connections, one to the pitot tube (pressure) and may or may not have another to the static. The static air (still) is obtained from slots cut into the side of the head at right angles to the air flow. (Ref. A.P.1275B. Vol.1. Sect.1. Chap.1).

(iii) Static vents - used to provide a source of static pressure having the advantage over the static of the pressure head in that the vent may be fitted where the position error is at a minimum. (Ref. A.P.1275B. Vol.1. Sect.1. Chap.3).

(d) Calibration of Airspeed Indicators

Several types of calibrators are available for the calibration of Airspeed Indicators and may be found in a form of a 'U' tube filled either with Mercury or distilled water.

The standard portable calibrator consists of two glass tubes, one immersed in water in a reservoir, and the other immersed in mercury in a reservoir. Adjustable

.../scales

scales are calibrated in M.P.H. and Knots, behind the tubes and the calibrator stands on three levelling screws and has its own spirit level. A connected block with a two way cock enables selection of water or mercury to be made, and it also carries an instrument connection and an adjustable pressure relief screw. The portable calibrator is fully described in A.P. 1275A. Vol.1, Sect.6. Chap.9).

For High Speed ranges a mercury 'U' tube is used in conjunction with the portable calibrator, and pressures from 450 to 700 knots can be read off.

5. RATE OF CLIMB INDICATOR (Ref. A.P.172A. Vol.1. Sect.1. Chap.8).

This instrument is a sensitive differential pressure gauge indicating rate of climb or dive in 1,000 ft/min. The static pipe line connection admits atmospheric pressure direct to a capsule, and then through a calibrated leak into the airtight case. If the atmospheric pressure decreases (as when climbing) the pressure in the capsule will simultaneously decrease, but the pressure decrease in the case will lag behind due to the calibrated leak, giving a constant pressure difference for a constant rate of climb. The capsule will collapse to a position relative to the pressure difference, causing the pointer to move over the "climb" scale and indicate a rate of climb, Similarly when diving the capsule will expand and the reverse happen.

During level flight the pointer should indicate zero. A zero setting device is incorporated for adjustment of the pointer.

(a) Calibration of Rate of Climb Indicators

Calibration is carried out by admitting or decreasing the pressure of the air in a test chamber in which the instrument is placed. A barometer or Vacuum Indicator is tied in, and from it the rate of climb or descent is measured for a certain length of time. (Ref. Appendix to appropriate chapter).

6. MACHMETERS (Ref. A.P. 1275B. Vol.1. Sect.1. Chap.2)

These are used on high speed aircraft to indicate the ratio of true airspeed to the speed of sound, this ratio being known as the Mach Number. In certain high speed aircraft, at speeds approaching that of sound, a dangerous aerodynamic condition may arise if the Mach Number for the particular type of aircraft is exceeded. On the instrument an adjustable lubber mark is provided which may be set to this number.

The speed of sound is proportional to the square root of the absolute temperature, and in the Machmeter instead of using temperature for operation of the instrument, we use an aneroid movement. This being because the speed of sound varies the same as the temperature for varying heights (I.C.A.N. law), and by using a height mechanism greater accuracy can be obtained.

The machmeter consists of a capsule operated by pitot pressure and an aneroid pile of three capsules. These capsules are so arranged that an alteration of pitot and static pressures, either one or the both together, result in a movement of the pointer. The operating arm of the aneroid is pivoted in the operating arm of the airspeed mechanism and has movement similar to that of a universal joint. This arm bears on another arm which is connected to the pointer quadrant.

(a) Calibration of Machmeters

Full details of apparatus, tests and tolerances are given in A.P. 1275B. Vol.1. Sect.1. Chap.2. Appendix 'I').

.../7.

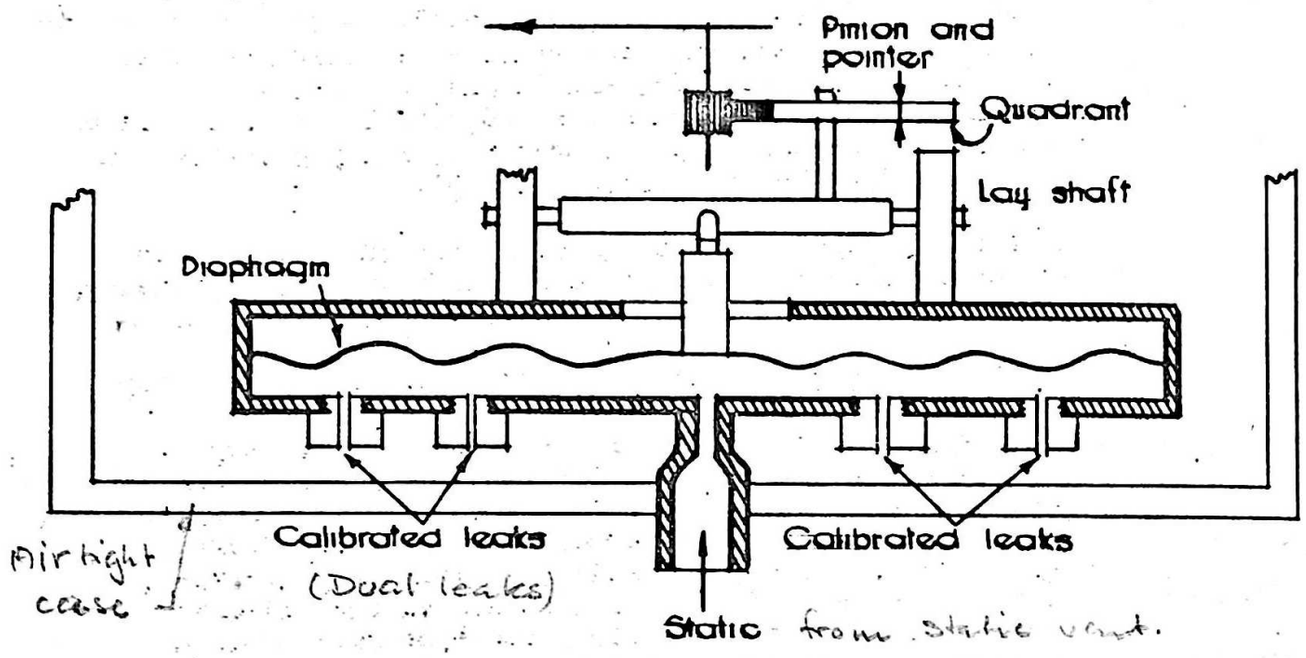


FIG - 12 - RATE OF CLIMB INDICATOR

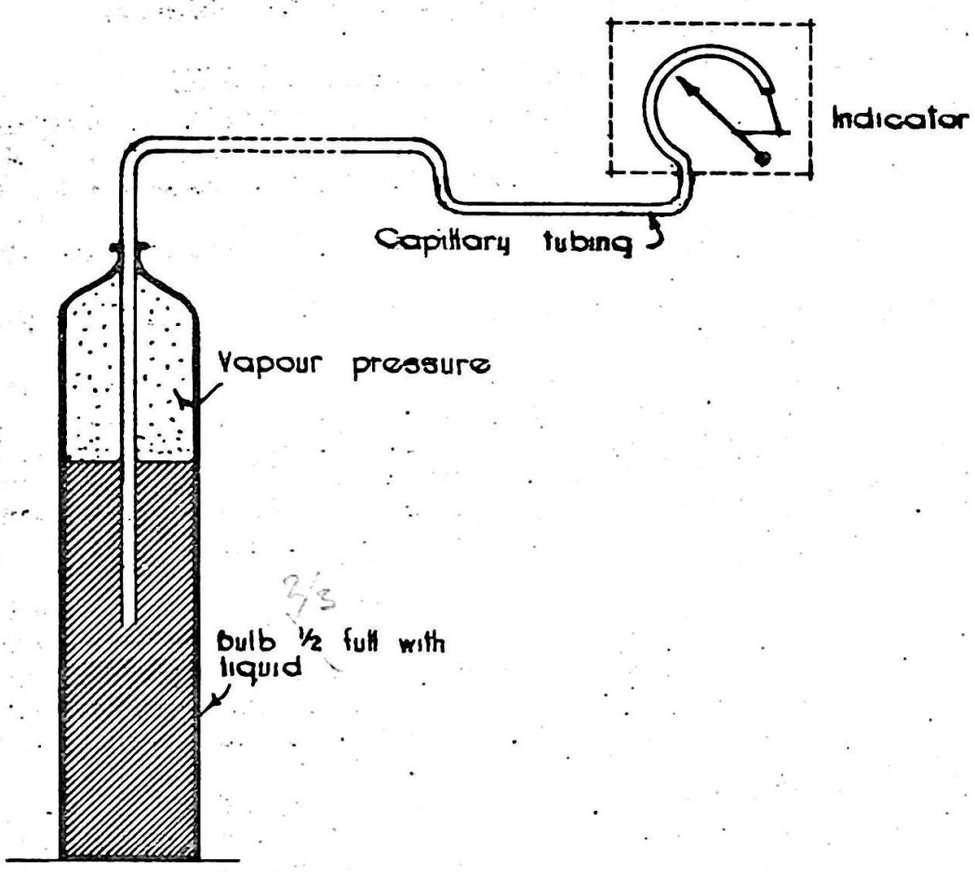
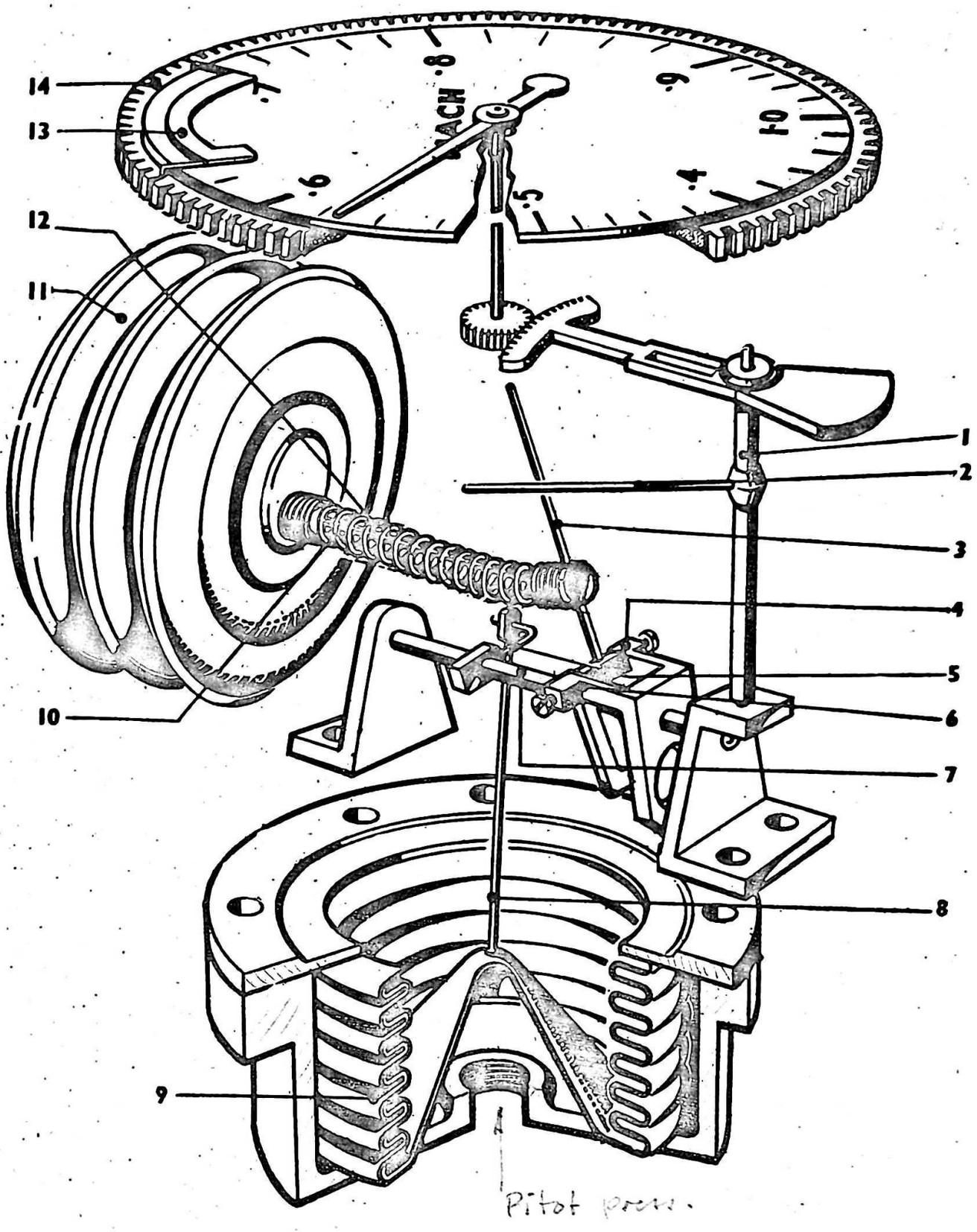


FIG - 13 - TRANSMITTING RADIATOR THERMOMETER



1 SECTOR SHAFT
2 SECTOR CONTROL ARM
3 OPERATING ARM
4 OPERATING ARM SUPPORT BLOCK
5 SYLPHON CRANK ARM
6 TRUNNIONS
7 LAYSHAFT
8 CONNECTING ROD
9 SYLPHON
10 ANEROID CASPULE PIN
11 ANEROID CAPSULE
12 TENSION SPRING
13 LUBBER MARK
14 LUBBER MARK TOOTHED PLATE

Part-sectioned view of mechanism (Mk. 1)

Fig 14. Machmeter.

7. THERMOMETERS

There are several types of thermometers in the service for many uses. They are normally calibrated in degrees and may be divided into three main types:-

(a) Transmitting
(b) Direct
(c) Electrical

and are used for measuring air, oil, coolant and gas temperatures.

(a) Transmitting Radiator Thermometer. (Ref. A.P.1275A. Vol.1. Sect.4. Chap.4.)

This instrument operates on vapour pressure using a highly volatile liquid. It consists of a bulb connected by capillary tubing to a bourdon tube in the indicator. The bulb is approximately 2/3 full with liquid and capillary tube extends half way into the bulb, so that if the bulb is tilted to any position the end of the capillary is still immersed in the liquid. The scale commences at 40°C because the liquid vapourises at that temperature, and the scale is cramped at the beginning, the operating pressure obeying a square law.

(b) Transmitting Oil Thermometer (Ref. A.P.1275A. Vol.1. Sect.4. Chap.2).

This again is a capillary type instrument, again consisting of a bulb, capillary and an indicator with a special type of bourdon tube. The whole instrument is completely filled with mercury and is therefore made of steel, the bulb being plated, and the steel capillary being covered with an external copper covering.

It can be seen that any change in temperature on the bulb (which contains nearly all the mercury) will cause expansion of the mercury and operate the bourdon tube.

The bourdon tube has no link and quadrant or pinion mechanism, the pointer being attached to the bourdon tube by means of a bi-metallic link. The tube itself is of thin cross-section wound in the form of a double spiral, the capillary being joined to the fixed end. By using a double spiral the pointer moves concentrically, and the connecting bi-metallic link compensates for ambient temperature.

(c) Transmitting Air Thermometer (Ref. A.P.1275A. Vol.1. Sect.4. Chap.3).

This instrument is similar in construction and operation as the transmitting oil thermometer, except that the bulb is much longer and thinner. The range of the instrument is -35°C to + 50°C. The bulb is fitted externally on the aircraft and is covered by a sun shield to protect it from the direct rays of the sun, but allows air to flow round the bulb to obtain the true air temperature.

(d) Direct Reading Air Thermometer (Ref. A.P.1275A. Vol.1. Sect.4. Chap.5).

This instrument is graduated from -60°C to + 50°C and is operated by a bi-metallic spiral. A change of temperature causes a difference of expansion of the two metals, and a closing or opening of the bi-metallic spiral. One end of the spiral is fixed and the other end is fixed to the pointer. It is fitted with a sun shield and holes in this shield allows the air to circulate about the bulb.

.../(e)

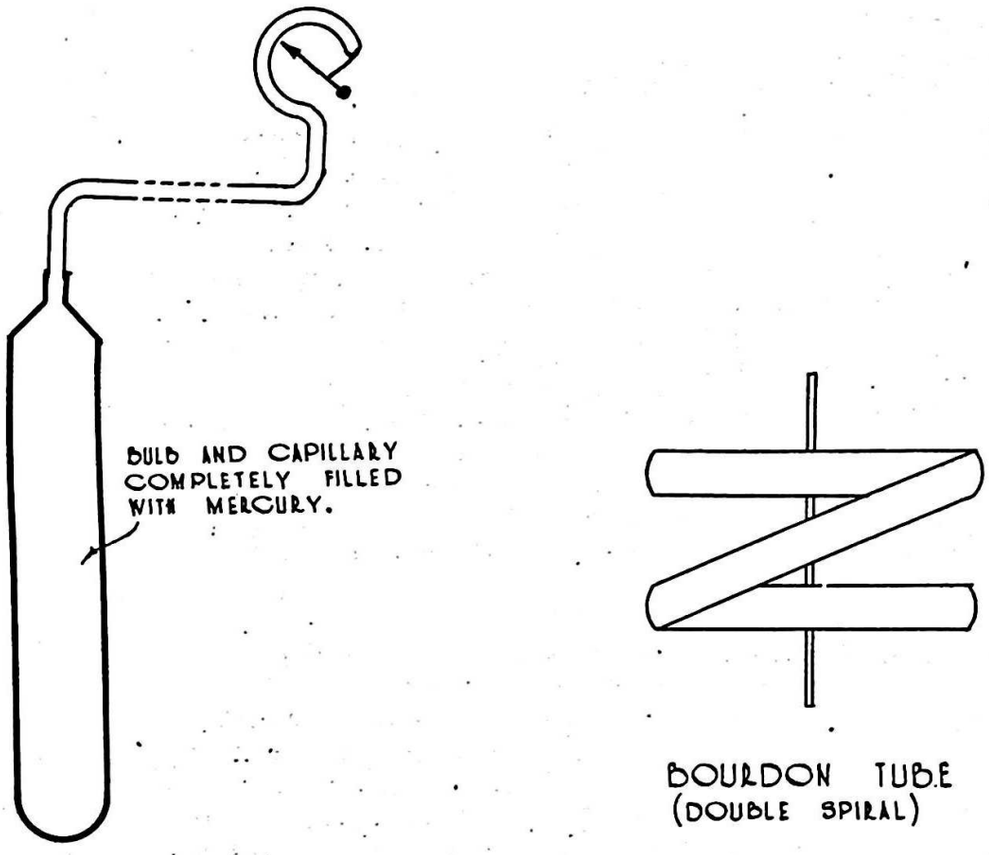


FIG 15 TRANSMITTING OIL THERMOMETER.

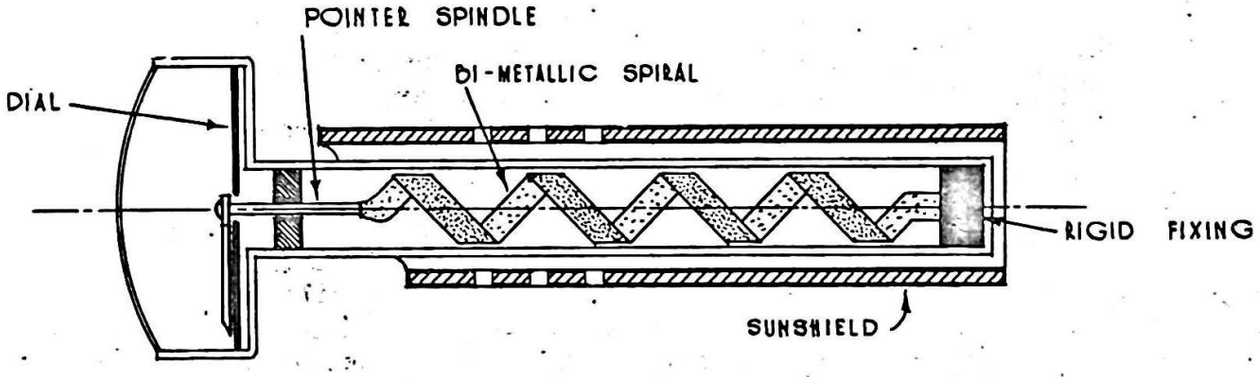


FIG.16 DIRECT READING AIR THERMOMETER

(e) Precision Thermometers. (Master)

These are the normal mercury in glass thermometers and are used for calibration purposes. They are contained in a wooden case, along with a National Physics Laboratory Certificate which gives the errors at varying temperatures. The thermometer readings are only correct when the whole of the mercury is immersed.

(f) Electrical Thermometers

There are two types of electrical thermometers in use in the service for use for air, oil or coolant temperatures. They are similar in construction but differ in their principle of operation, consisting of an indicator connected by ordinary electrical leads to a bulb.

(i) The Thermometer Bulbs are identical for both types and consist of a temperature sensitive resistance wound on a bakelite rod and contained in a nickle plated brass bulb. A maker's balancing resistance is also incorporated. The bulb of the oil and coolant thermometers are identical, but that for the air thermometer consists again of a temperature sensitive resistance mounted on a flat plate which is fitted flush to, and insulated from the aircraft's skin. Any change in temperature will alter the value of the resistance of the bulb.

(ii) The Wheatstone Bridge type Indicator consists of three arms of fixed resistances, the fourth arm being the bulb or sensitive arm. Variations in temperature of the bulb results in an unbalance of the bridge and an indication on the indicator which takes the place of a galvanometer. The scale is calibrated in degrees centigrade and the deflection of the pointer will indicate the temperature of the bulb.

(iii) The Ratiometer type is a moving coil instrument having two coils wound on the same former and placed in a non-uniform Magnetic field. When current flows in the coils, the torques produced act in opposition to one another, and the construction is such that the coil carrying the strongest current will move into the weaker part of the magnetic field. Rotation of the "former" and hence the pointer will continue until the torques are balanced. One coil is governed by a "fixed" resistance of low temperature coefficient contained in the indicator, and the other coil is governed by the sensitive resistance in the bulb. (Ref. A.P.1275A. Vol.1. Sect.4. Chap.2).

(g) Calibration of Thermometers

Non-electrical thermometers are calibrated by checking against a master precision thermometer in a heated fluid. For details of tests and apparatus see A.P.1275A. Vol.1. Sect.6. Chap.24.

For electrical thermometers the indicator is tested by using a calibrated resistance box marked in degrees centigrade; and the bulbs by heating to a known temperature and measuring their resistance. (See Appendix to A.P.1275A. Vol.1. Sect.4. Chap.2).
(Resistance box, ref. A.P.1275A. Vol.1. Sect.6. Chap.2).

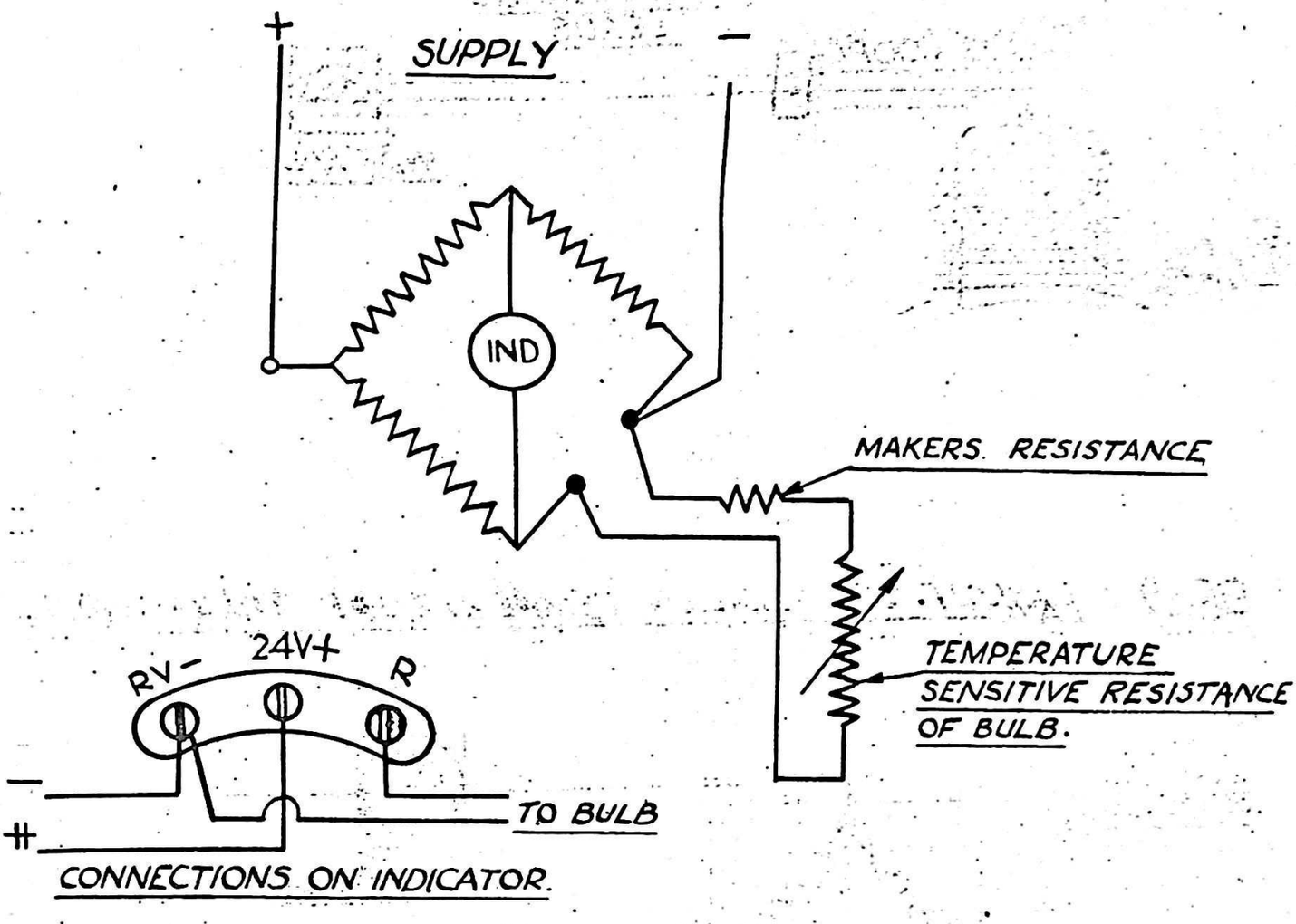


FIG 17 - ELECTRICAL THERMOMETER (WHEATSTONE BRIDGE)

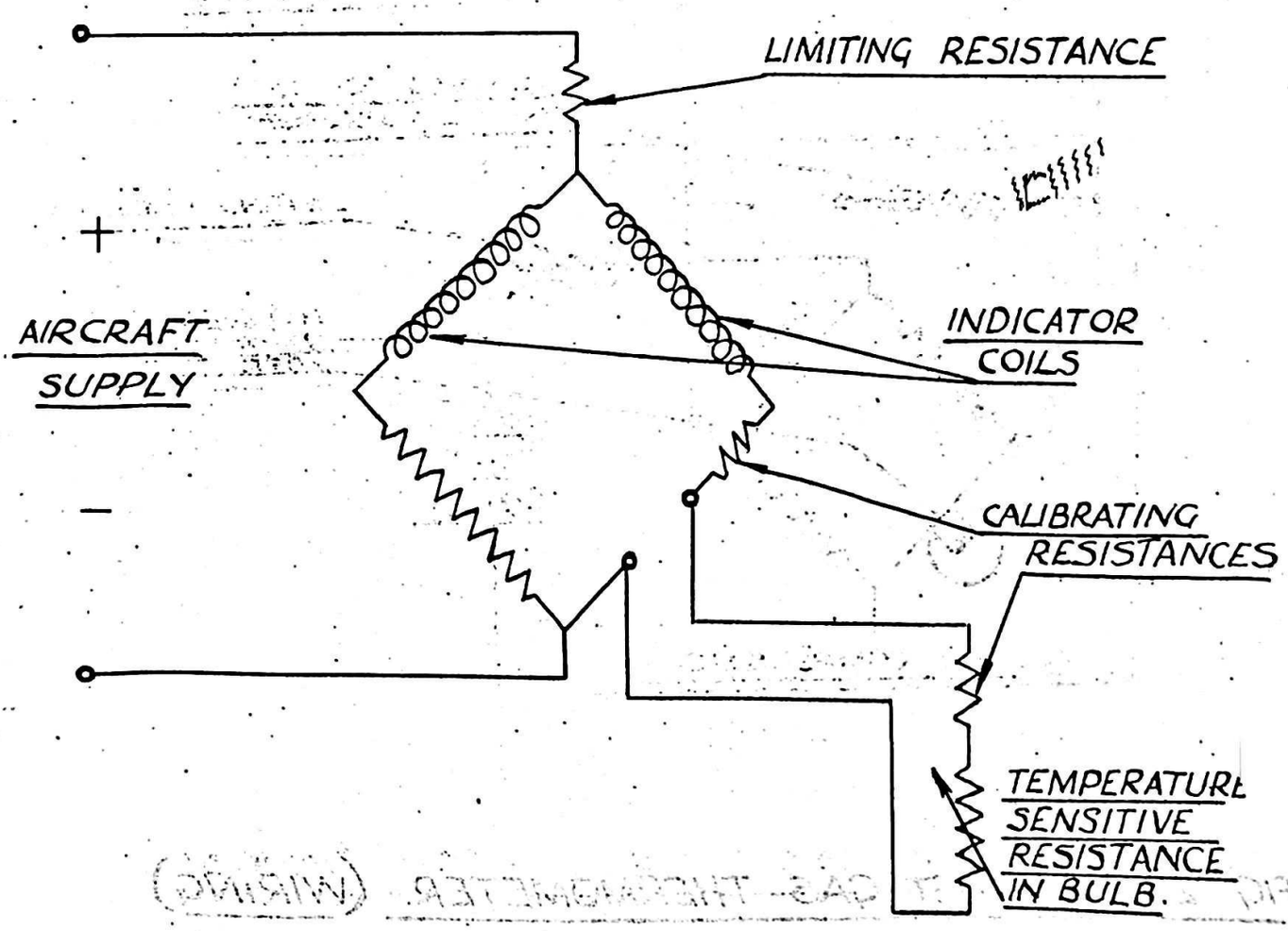


FIG 18. - ELECTRICAL THERMOMETER (RATIOMETER TYPE)

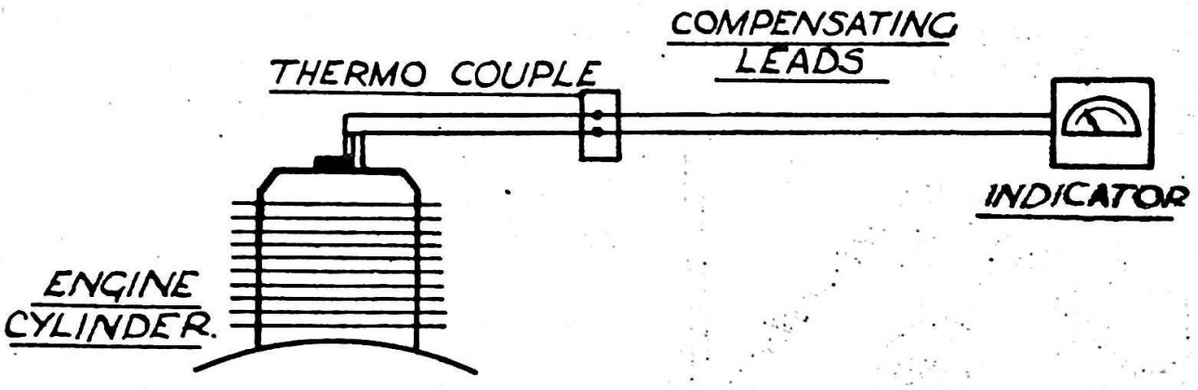


FIG 19 - LAYOUT OF CYLINDER. TEMPERATURE THERMOMETER.

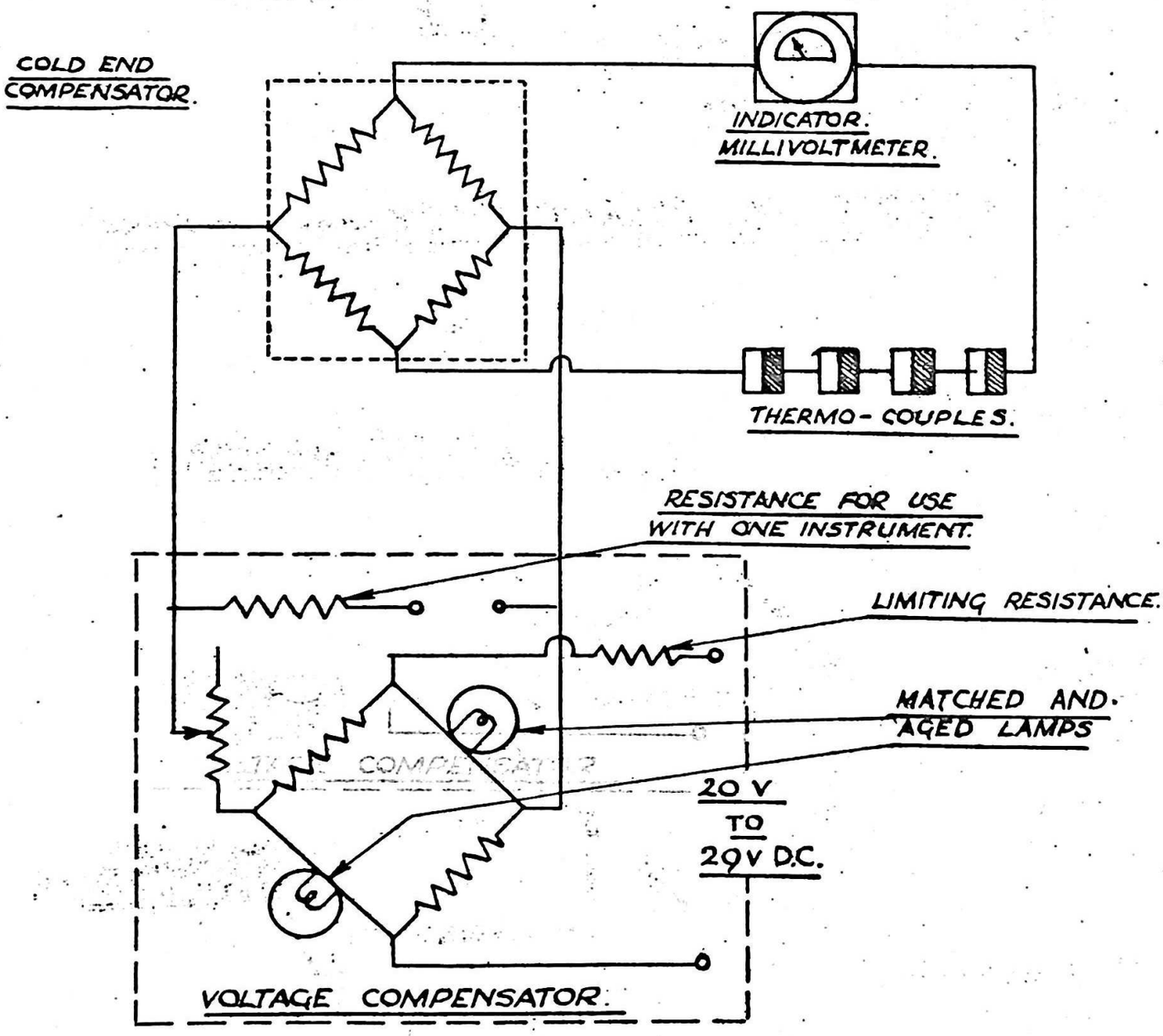


FIG 20 EXHAUST GAS THERMOMETER. (WIRING)

8. CYLINDER HEAD TEMPERATURE THERMOMETER (Ref. A.P.1275A. Vol.1. Sect.4. Chap.7).

This instrument is a normal thermo-couple pyrometer, which measures the difference between the hot and cold ends. Its operation depends upon the fact that when two dissimilar metals are joined together at both ends and heat is applied to one joint, a small E.M.F. is generated the amount depending on the metals used and the difference in temperature between the hot and cold junctions.

The complete instrument consists of an indicator, compensating leads and a thermo-couple.

(a) The indicator is a moving coil milli-voltmeter, having a scale graduated from 0° to 350°C, which is the cold junction. It is compensated by means of a bi-metallic spiral for ambient temperatures, and by a neutraliser for change of resistance of the coil for ambient temperatures.

(b) The compensating leads are made up of two conductors made of the same metal as the thermocouple (Constantin and Copper). The leads are supplied in varying lengths, but have the same resistance.

(c) The Thermo-couple consists again of two conductors joined together and suitably insulated. The joined point of the conductors are bolted to the cylinder head and in direct contact.

(d) Calibrations of the thermometer is carried out by using a test box. Details of tests are given in A.P.1275A. Vol.1. Sect.6. Chap.17).

9. EXHAUST GAS THERMOMETER

This instrument is used to measure the temperature of the exhaust gases of jet engines. It consists of four thermocouples placed in the exhaust stack, 90° apart and connected in series. The couples are sheathed to protect them from the velocity of the gases, and at 403°C their output is 65.6 M.V. (These form the hot junction).

The cold junction is formed by an unbalanced Wheatstone Bridge, known as the cold end compensator. The output from this bridge is 65.6 M.V. and acts in opposition to the thermocouple output, and so suppresses the scale of the indicator to start at 400°C. The indicator being a milli-voltmeter measuring the difference in voltage output, its scale calibrated from 400°C to 700°C.

If the input to the Wheatstone bridge varies, the indicator will also vary, and so it has to have a constant supply. The input to the cold end compensator is kept constant at 1.5 volts by means of another unbalanced Wheatstone bridge known as the voltage compensator.

The two opposite arms of this bridge are formed by two specially matched and aged lamps, which, if the supply increases, burn brighter, their temperature increases and hence their resistance increases, so maintaining the unbalance at 1.5 volts.

The voltage compensator allows for changes of supply voltages of 20 to 29 volts, and can be used for one or two engines and indicators. When used for single engine aircraft, a resistance is incorporated in parallel across the supply to the cold end compensator.

A limiting resistance is incorporated to reduce the supply voltage, and the output of the voltage compensator is initially trimmed off to 1.5 volts by a trimming resistance.

Compensation for change of ambient temperature of the cold end and also for the lamps is allowed for by each bridge having one of its resistances of a high temperature coefficient.

.../10.

10. ENGINE SPEED INDICATORS

(a) Mechanical Type (Ref. A.P.1275A. Vol.1. Sect.1. Chap.1)

Essentially a centrifugal governor operating a pointer over a dial calibrated in R.P.M.

The instrument shaft is rotated at engine speed by means of a flexible shaft running at quarter engine speed, stepped down in the engine and stepped up in the instrument.

A governor, rotated by, and pivoted on the instrument shaft is acted upon by centrifugal force, and its movement controlled by two involute springs. Hence the position of the governor is dependant on the speed of the instrument shaft, i.e. engine speed.

The movement of the governor results in movement of a sliding muff, up or down the instrument shaft, and this in turn is transmitted by means of a steel pin carried by the muff and attached to a quadrant engaging with the pointer pinion, moving the pointer over the dial.

(b) Electrical Types. (A.P. 1275A. Vol.1. Sect.1)

The electrical types are all similar and only vary slightly in construction and range. One type is used for jet engines and has a larger range, i.e. 0 - 20,000 R.P.M. They all consist of two components, or generator and an indicator.

(i) The Generator consists of a stator and a rotor; the stator fixed to the case or yoke and consisting of three separate windings of fine insulated wire wound on a laminated former in a "Star" fashion. The rotor is a four pole permanent magnet, and is rotated at $\frac{1}{4}$ or $\frac{1}{2}$ engine speed by means of a short flexible drive.

The out-put is A.C., and its frequency is dependant on the engine speed, and therefore this frequency output is the governing factor of the instrument.

(ii) The Indicators are similar in operation and vary only in range, and that they may have one or more pointers. The mechanism consists of a three-phase, self starting synchronous motor, operating a magnetic drag cup element which is coupled to the pointer mechanism.

The motor is squirrel caged having three stator windings wound in a "Star" fashion and connected to the phase windings of the generator. Thus the generator sets up a rotating field, its speed depending on the frequency output of the generator, and the rotor revolves at the speed of the field, and therefore engine speed.

A magnetic drag element consisting of a cruciform magnet and a copper drag cup is mounted co-axially with the rotor. Around the magnet is placed a magnetic screen, to ensure even distribution of the field. The copper drag cup is rotated by eddy currents induced by the rotating magnet, but is controlled by means of a hair-spring, and its movement is conveyed by means of gearing to the pointer.

(c) The Tinsley Stroboscope, is used for the calibration of engine speed indicators. It consists of a disc with varying number of holes cut in it at varying radi, and rotated by means of a variable speed motor, and at the same speed as the instrument under test.

.../Behind the

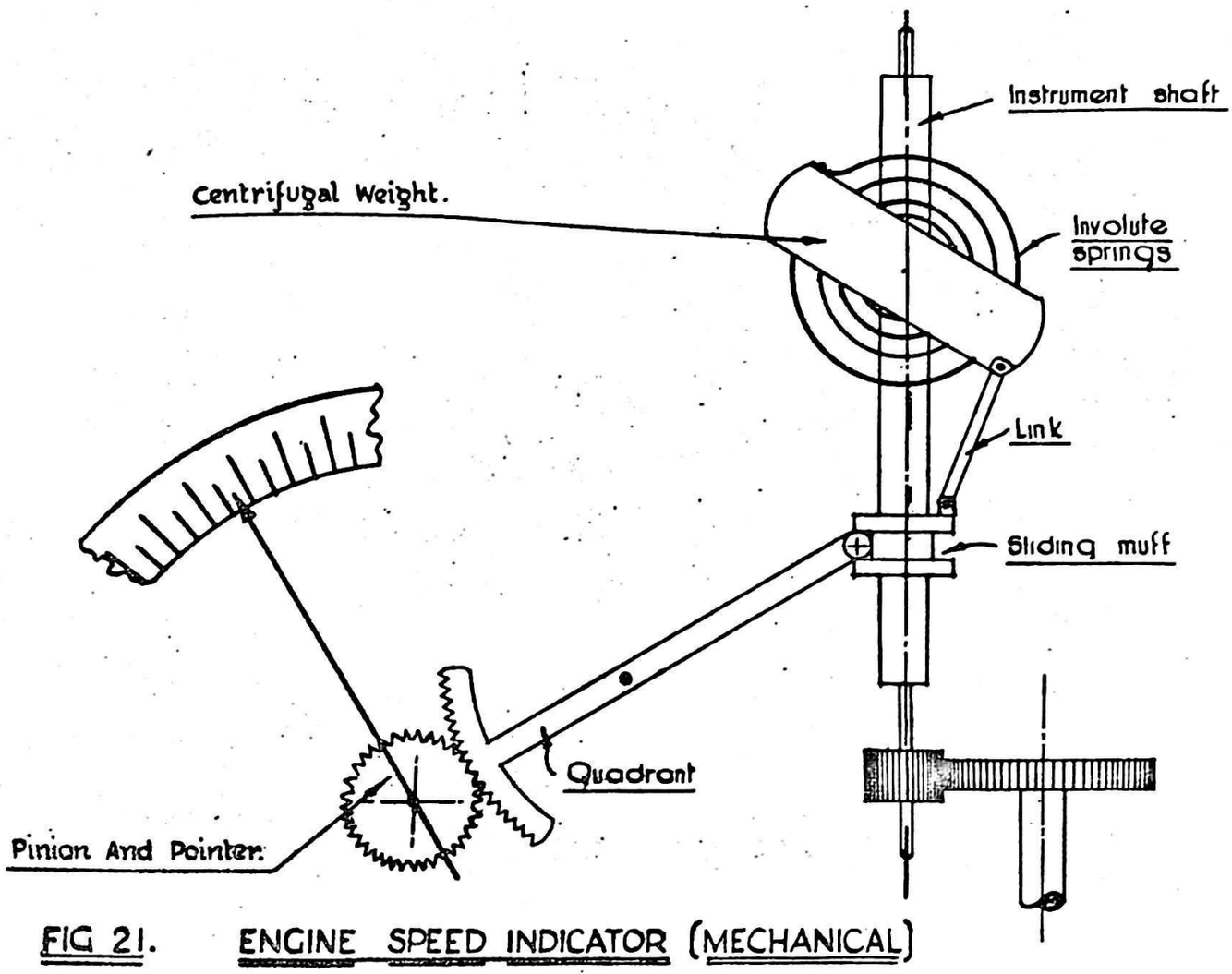
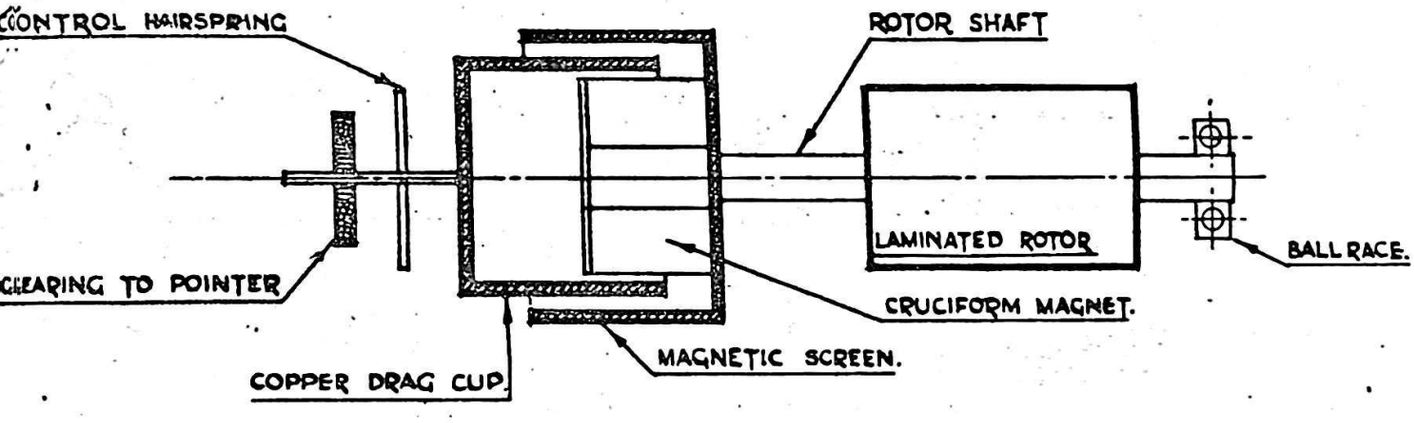


FIG 21. ENGINE SPEED INDICATOR (MECHANICAL)

INDICATOR.



THEORETICAL WIRING DIAGRAM

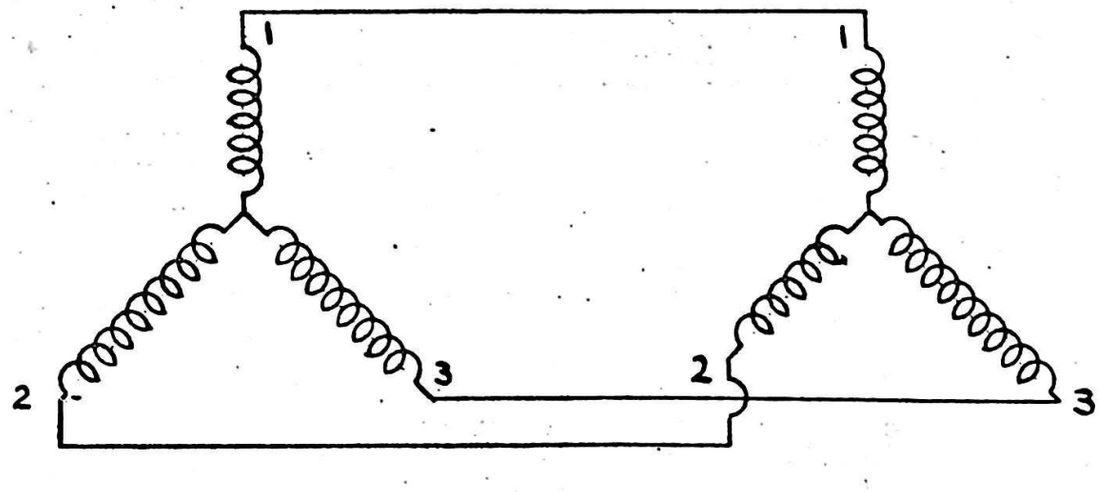
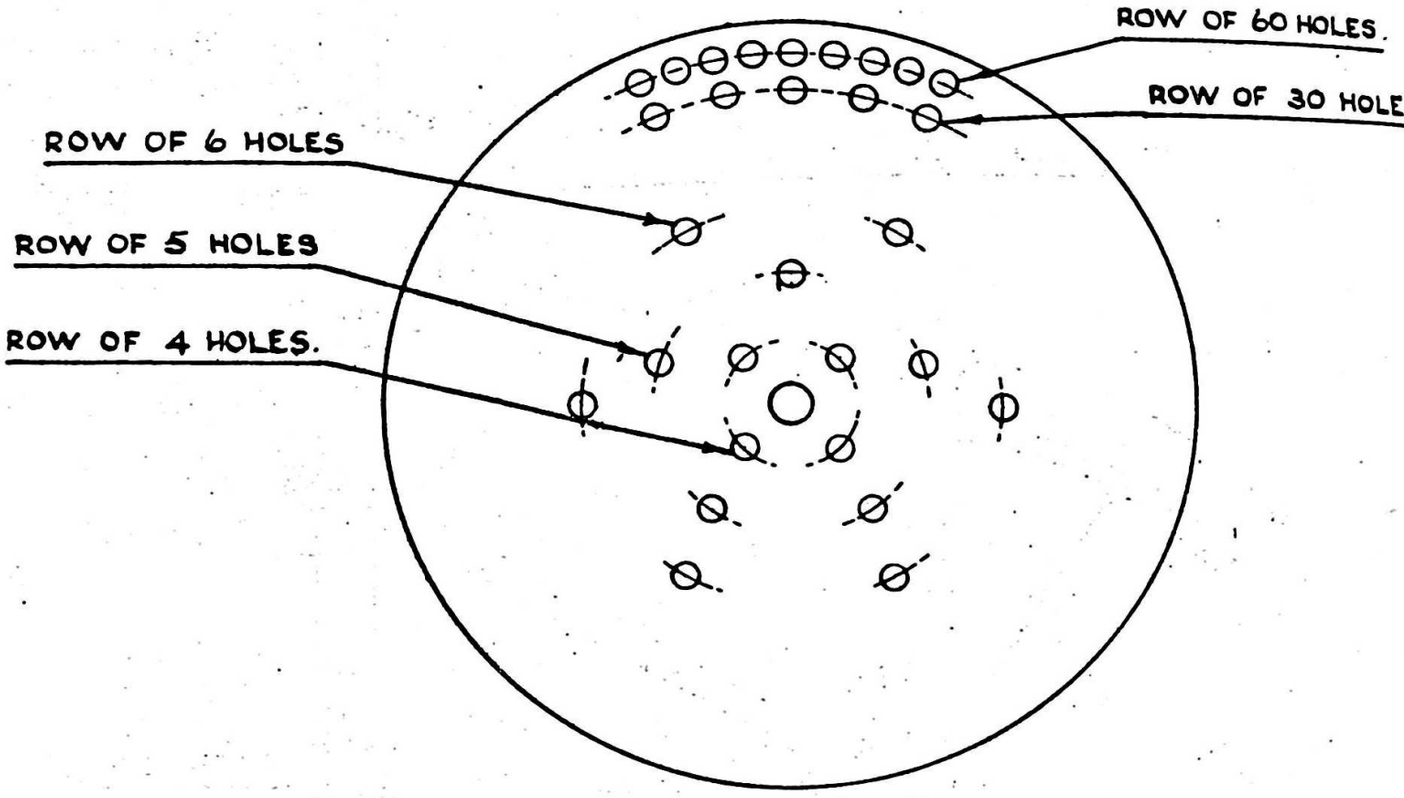
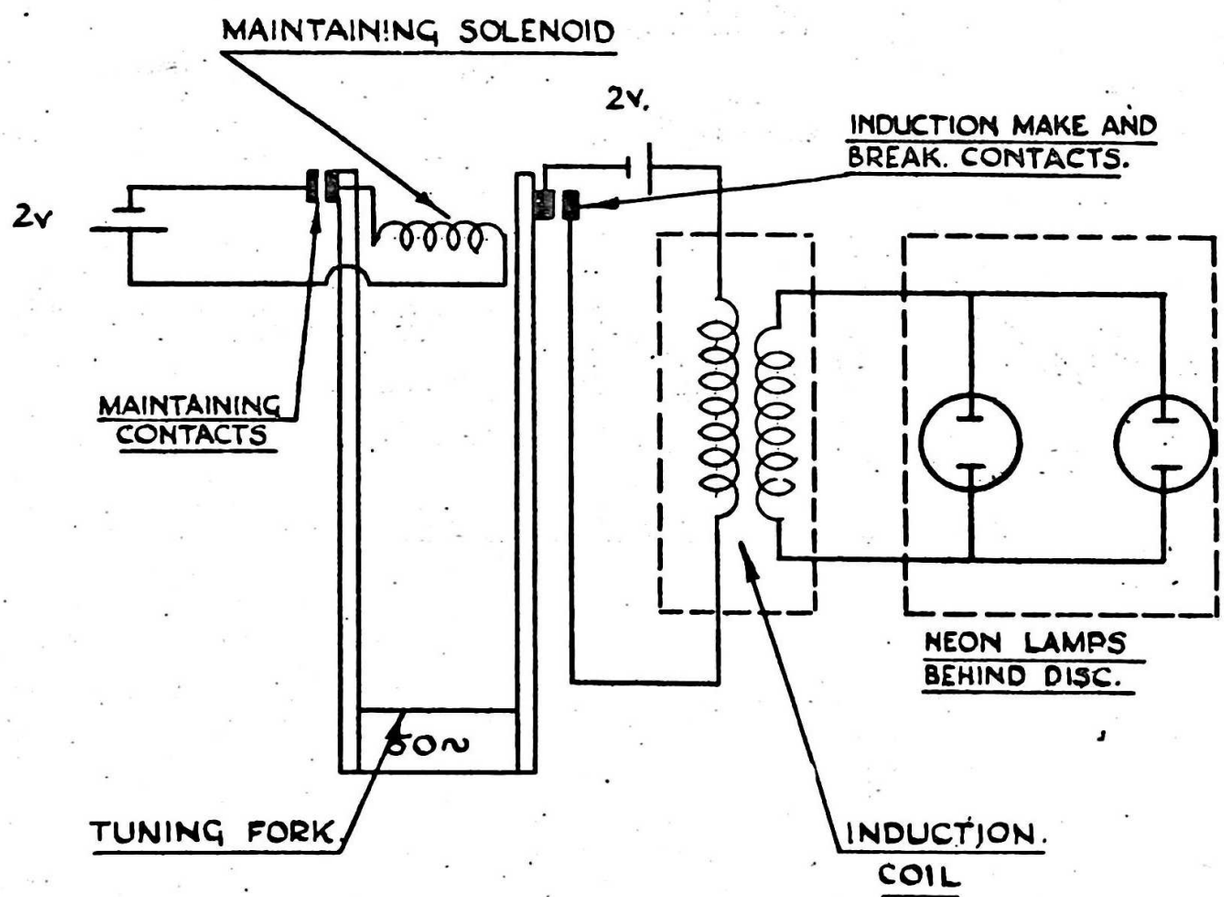


FIG 22 ENGINE SPEED INDICATOR (ELECTRICAL)



A. DISC. OF STROBOSCOPE.



B. WIRING DIAGRAM.

FIG 23. TINSLEY STROBOSCOPE.

Behind the disc are two Neon Lamps which flash 50 times a second controlled by a pair of contacts on a tuned fork vibrating at 50 cycles a second. A second pair of contacts on the fork operate a solenoid which maintains the amplitude of vibration of the fork.

For varying speeds of rotation of the disc the holes will be in various positions, and if one hole is in the same position for two consecutive flashes of the lamp, it will appear stationary, due to "persistance of visions" of the eye, the eye retaining the first image until the second flash appears.

As there are varying numbers of holes, at varying speeds they will appear stationary; also at multiples of that speed.

The row of 60 holes will appear stationary at 50 R.P.M.
" " " 30 " " " " "100 R.P.M.
" " " 6 " " " " "500 R.P.M.
" " " 5 " " " " "600 R.P.M.
" " " 4 " " " " "750 R.P.M.

(Ref. A.P.1275A. Vol.1. Sect.6. Chap.1)

11. DESYNN TYPE INSTRUMENTS (Ref. A.P.1275A. Vol.1. Sect.3)

The desynn system as applied to various types of instruments, is a remote indicating system, and consist of two parts, the transmitter and indicator connected by suitable electrical leads.

The transmitter is an evenly wound, continuous circular resistance of fine wire, with three tappings taken from it at 120° apart. Moving over and bearing on this resistance are two wiper arms, insulated from each other and connected to the aircraft D.C. supply. The P.D. measured across the tappings will vary with movement of the wiper arms which are free to rotate and are 180° apart.

The indicator has three coil 120° apart and connected to the corresponding tappings on the transmitter. Current flow in these coils will set up a magnetic field about each coil, the strength and polarity of which will vary with the position of the transmitter arms.

A permanent magnet pivoted in the field and free to rotate will align itself with the field, and the pointer fitted directly to this permanent magnet will record the angular movement f the wiper arms. A weak permanent magnet is fitted so as to return the pointer to its electrical zero when the circuit is broken.

This system has been adapted and used for several instruments requiring remote operation.

(a) Position Indicators (flap, gun, turret, etc.). Movement of the item, e.g. flap operates a transmitter and hence the indicator.

(b) Fuel Contents Gauges

The transmitter is a cork float carried on a braced arm geared to an ebonite crank by means of a gear and pinion. A spigot fitted to the crank engaged in a slot cut in a fibre arm attached to the transmitter wiper arm. The transmitting unit is fitted to the fuel tank and the amount of fuel in the tank governs the position of the float and hence the position of the wiper arms. Tank units are not interchangeable between different tanks.

.../The indicator

The indicator is a normal desynn indicator calibrated in gallons, and again is not interchangeable except when used on the same type and capacity tank.

(c) Desynn oil Pressure Gauges

The indicator may have single or dual dials calibrated in lbs. per square inch.

The transmitter consists of a sylphon bellows which is connected to the oil pressure system by means of a flexible connection. Increase in oil pressure will result in expansion of the bellows, and this movement is transmitted by means of a "bell-crank" system to two wiper arms bearing on two cylindrically wound resistances. The wiper arms are insulated from each other and current is supplied to them by two hairsprings.

Tappings from the resistances are interconnected and the transmitter functions in the same manner as a normal desynn transmitter, except that the wiper movement is linear instead of circular.

A choke is fitted to the pressure inlet to counteract pressure surges:
(Ref. A.P.1275A. Vol.1. Sect.3. Chap.5).

(d) Testing of Desynn Instruments

A portable desynn test set is supplied which will test either indicator or transmitter. It is in effect a Master Transmitter and a Master Indicator, selection being made by a switch.

The colour blocks on the transmitter and indicator denote the limits for particular instruments.
(Ref. A.P.1275A. Vol.1. Sect.6. Chap.).

12. FUEL PRESSURE WARNING UNITS

These are used to indicate to the Pilot when the engine fuel pressure drops below a safe level. The warning consists of a red light operated by a switch, in turn operated by a diaphragm, one side of which is connected to the fuel pressure system.

The switch contacts may be set for any required pressure. A resistance unit is incorporated in the circuit, with alternative connections for 12v or 24v D.C.

(Ref. A.P.1275A. Vol.1. Sect.1. Chap.11).

13. WATCHES

The driving power of a watch is derived from its mainspring, which operates through a train of wheels, and is released at an even rate by the escapement. The Balance wheel and hairspring control the movement of the escapement and thereby regulate the movement of the wheels and hands, i.e. alteration of the balance wheel and or hairspring alters the timing of a watch.

.../The Balance

The Balance Wheel is a bimetallic rim on a pivot free to rotate but constrained by a hairspring, and made to swing about the null position of the hairspring. At the bottom of the balance wheel staff is an impulse roller which engages in the forked tail of the escape lever.

The Escape Lever is in the form of a pivoted Tee, its tail is forked and each arm of the Tee holds an oblong jewel called pallet stones. These pallet stones engage alternately with the escape wheel teeth as the lever is moved from side to side by the balance wheel, and at each movement allows the escape wheel to move one tooth at predetermined and constant intervals.

As the escape wheel is under tension from the mainspring, it is so constructed so that as the lever moves, a force is imparted to the lever towards the end of its travel, and it "flicks" over; the tail of the lever imparting this force to the balance wheel and makes it swing further until stopped by the hairspring tension.

When the balance wheel reaches the end of its swing the hairspring is in tension and will make the balance wheel swing in the opposite direction and the reverse action takes place and another tooth of the escape wheel is released. Clocks are similar to watches but may have a pendulum instead of a balance wheel. The action is similar

Timing

Pendulum clocks - lengthening pendulum slows clock.

Balance wheel - lengthening hairspring slows clock or watch.

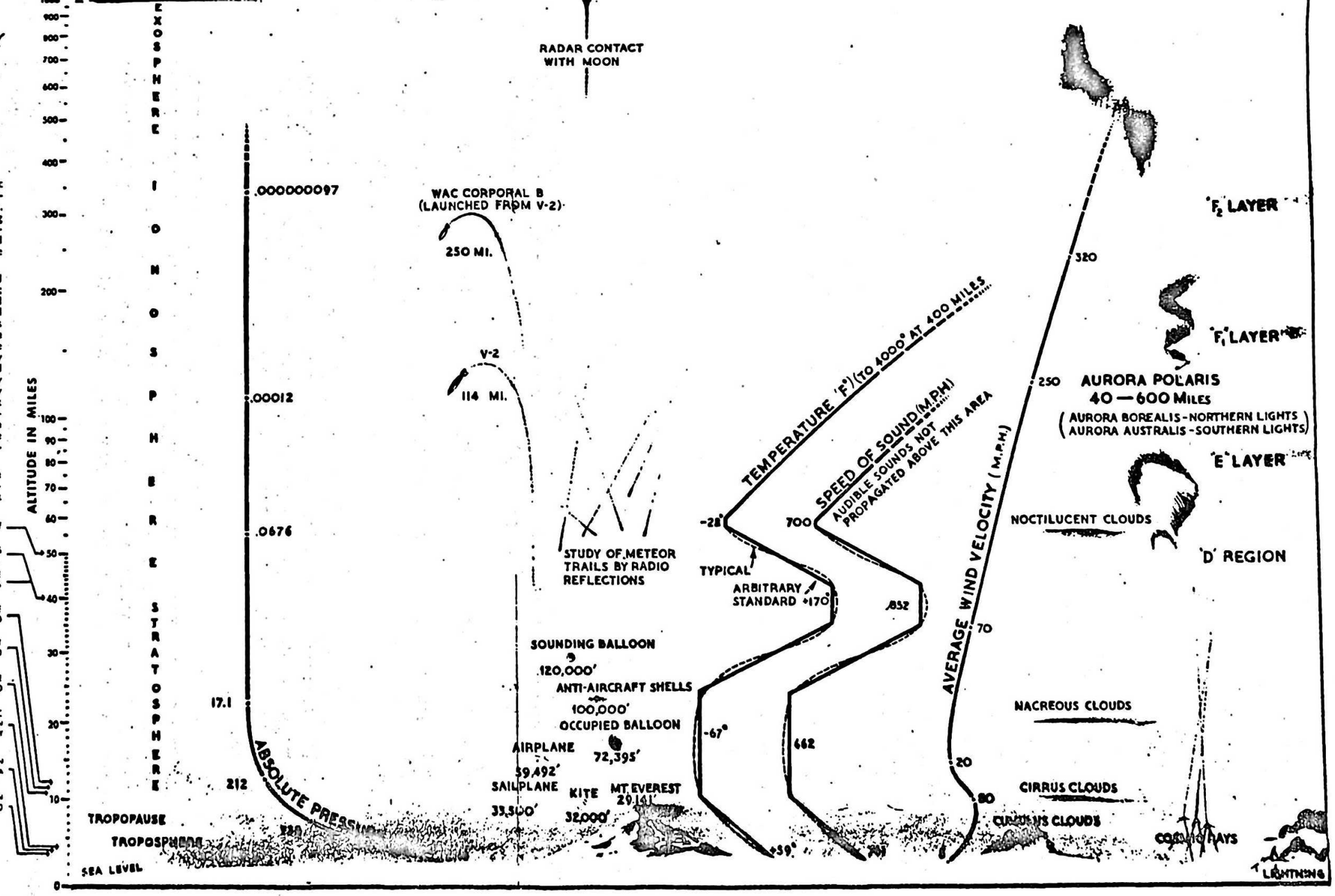
Temperature should not affect a good watch, compensation is by means of a bimetalling rim balance wheel on which are small screws which affect adjustment, and once set should not be touched unless Balance wheel has been repaired.

Characteristics of the Earth's Atmosphere

ACKNOWLEDGE of the earth's atmospheric characteristics is important to air transportation as well as to weather prediction, radio communications, and the understanding of various phenomena that occur in our everyday lives. Although there are many unsolved problems, the advances during the past decade in this field have been outstanding.

The earth's atmosphere is currently defined as consisting of four concentric gaseous layers: the troposphere, stratosphere, ionosphere, and exosphere. These layers provide a gradual transition from the atmospheric characteristics as we know them at sea level, to the exosphere which merges with interplanetary space. The weight of this atmosphere is approximately one-millionth of the weight of the earth, and a square foot column extending vertically through the atmosphere weighs approximately one ton. Of this atmospheric weight about three-quarters is concentrated in the troposphere, slightly less than one-quarter in the stratosphere, one three-thousandth in the ionosphere, and one one-hundred-thousand-millionth in the exosphere.

Atmospheric characteristics vary with time of day, latitude, and season of the year. Consequently, only representative average values are shown.



LEVELS. The first layer of the earth's atmosphere, the troposphere, extends from sea level to about 35,000 ft. at middle latitudes, but varies from 54,000 ft. at the equator to 28,000 ft. at the poles. This densest layer is approximately four-fifths molecular nitrogen and one-fifth molecular oxygen. The tropopause is the boundary between the troposphere and the stratosphere; the stratosphere extends 60 to 70 miles.

ABSOLUTE PRESSURE. As distinguished from other characteristics of the earth's atmosphere, the vertical pressure distribution behaves in a regular manner and constantly decreases with altitude. At the outermost edge of the troposphere, the pressure has fallen to one quarter of its sea level value; at the limit of the stratosphere it has fallen to one three-thousandth of the sea level value.

TEMPERATURE. The temperature in the troposphere steadily decreases with increasing altitude. In the stratosphere, the temperature is at first constant, then increases to a maximum in the ozone layer. The temperature then starts to decrease again and reaches freezing temperatures just inside the ionosphere at the noctilucent cloud level, then increases to a maximum of about 4,000 (F.) in the exosphere.

SPEED OF SOUND. The speed of sound is proportional to the square root of the absolute temperature. However, as the distance between the molecules increases at the high altitudes, sound waves of the frequency corresponding to a piano scale are damped out in very short distances. The maximum altitude at which a given sound wave can be propagated increases as the sound wave length increases

PREPARED BY ENGINEERING DEPARTMENT
DOUGLAS AIRCRAFT COMPANY, INC.
EL SEGUNDO PLANT, EL SEGUNDO, CALIFORNIA.

ELECTRICAL & INSTRUMENT SECTION

HENLOW DIVISION, R.A.F. TECHNICAL COLLEGE

INSTRUMENT WORKSHOP PRACTICE

Instrument Precis No. 8

Basic Fitting

1. GENERAL

The functions of aircraft instruments vary considerably and involve a knowledge of electrics, electronics and pneumatics etc., besides general engineering principles. In their design, size and weight are important and must always be considered.

Most instrument mechanisms are very delicate and finally balanced, and must not on any account be jarred or knocked. When installed in aircraft they are usually on panels protected from vibration.

Repairs to instruments are limited in the service, except on Service Repair Depots where full facilities are available to carry out any type of repair.

2. INSTRUMENT REPAIR SHOP

No firm rule can be applied in regard to size or layout of an Instrument Repair Shop, as these depend upon capacity and type of work undertaken, but the following requirements should be kept in mind.

(a) Lighting - Should be adequate for all work on either bench or machine. Separate lighting for each workman at the bench is essential and the position of the light should be adjustable. Poor lighting makes work tedious and can cause eye strain.

(b) Heating - The workshop should be sufficiently warm to ensure easy manipulation of small parts. A cold workshop produces clumsy work, while a workshop overheated causes contamination due to perspiration. Air conditioning is ideal, with temperature at about 60° to 65°F.

(c) Benches - should be of normal height for standing and working at a vice. They should be covered with linoleum. Metal coverings must be avoided, as these can cause "shorting" of electrical equipment. Stools should be available for use at the bench when stripping, assembling and testing instruments, and when using a watchmaker's lathe. Stools reduce fatigue considerably.

(d) Floor - Wherever practicable the floor should be covered with linoleum or similar material. Possibility of dust must be kept to a minimum.

3. WORKSHOP TOOLS

(a) General. The following tools will be found to be useful, but all tools in the Workshop will naturally depend upon the type of work being undertaken.

(i) Vertical Drilling Machine ($\frac{1}{4}$" chuck)
(ii) Grinder - for lathe tools, drills, etc.
(iii) Engraving machine - For preparation of new dials etc.
(iv) Lathes - Watchmaker's lathes and necessary tools and attachments. An additional 4" lathe for heavier work.

(b) Individual Kits. Service issue tool kit as laid down in A.P.830. These kits should be inspected periodically to ensure serviceability of all tools. It is emphasised that all tools must be kept in a first class condition.

(c) Precision Tools. These include micrometers, vernier gauges, depth gauges, dial test indicators, etc. They should only be issued to individuals when required for use. Their accuracy should be checked periodically.

(d) Specialist Tools and Jigs. These tools and jigs will vary, depending on the type of instrument under repair. Jigs will normally be for one type of instrument and, like tools, should be always kept serviceable.
Specialist tools may include the following:-

Pin vices and tongs
Drills and broaches (instrument makers' and watchmakers').
Soldering Irons
Spirit lamps and blow pipes
Geneva files
Watchmakers' punches and stakes
Pointer extractors
Douzieme gauges,

and others.

4. METHOD

(a) Cleanliness and Neatness
Cleanliness is essential as damage to instruments can be caused by dirt. Neatness in bench work leads to speed and efficiency.

(b) Accuracy in Manufacture and repair
Accuracy to within limits laid down should always be adhered to. Latitude may be allowed only as a last resort, and then only when accuracy and interchangeability are not affected. This latitude must never be abused. Repairs should look like new parts and must always be thoroughly inspected and tested as required.

(c) Finish
This is of prime importance. All working surface should be highly polished to reduce friction. Other surfaces should be free from rust and corrosion. Perspiration marks, if left on steel pivots, will cause rust in a very short time.
The external finish and the dial of an instrument should be as clean and neat as on a new item from a manufacturer's assembly line.

(d) Materials used in construction of Instruments.
Many metals and plastics will be found to be used in the construction of instruments, typical uses are:-

(i) Brass - plates, small moving arms and levers, gearing, screw, etc.
(ii) Steel - pivots, ball races, springs.
(iii) Phosphor Bronze - springs and bearings.
(iv) Copper - tubing (usually surface treated).
(v) Light alloys - Main castings, and sometimes cases.
(vi) Special alloys - these have specific uses such as capsules, Bourdon tubes, compensating mechanisms.
(vii) Plastics - insulating parts, cases.

.../(e)

(e) Locking of nuts, bolts and screws
Besides methods used in general engineering procedure, such as lock nuts, spring and tab washers, in instrument work, shellac and bakelite varnish are used to lock small nuts and screws, etc. Varnish is applied to the nut, to the screw head or to the screw thread on assembly.

(f) Bolts and Screws
The size of bolts and screws used on instruments is usually in the B.A. range, i.e. OBA to 10BA. In watches, threads are standard watch threads of metric sizes.

(g) Use of Tools
When using a spanner or screwdriver, it is essential that it should fit the screw head or nut correctly. Damaged screw heads and burred nuts show had workmanship and are also very difficult to remove without causing further damage.

5. SPECIALIST TOOLS

(a) Soldering Irons - when used, size must be considered in relation to the work to be carried out.

(b) Blow Lamps - used for heating, brazing and tempering. Large objects only.

(c) Spirit Lamps - filled with Methylated spirits, which gives a clean hot flame. Used for heating and tempering small items. They are used in conjunction with:-

(d) Watchmaker's Blowpipe - used in the flame of a spirit lamp, to concentrate heat onto a small area.

(e) Broaches - in sets of 60 in graduated sizes. Tapered and used for enlarging holes.

(f) Toolmakers Clamps - useful for gapping any small part when work is to be done on it.

(g) Geneva Files - used by watchmakers and instrument makers for shaping small items. They are obtainable in varicus forms and cuts, and are very fine.

(h) Pivoting File - is a double - ended file, having one end of a very fine cut, the other end being a ground burnisher. It is used for forming and polishing steel pivots.

(j) Essence Jars - Glass jars with lids, primarily for holding cleaning fluid, but also used for holding small parts.

(k) Cover Glasses - small glass covers on a Wooden base, under which items can be placed uhtil required, keeping out dust.

(l) Pin Vice and Tongs - used to hold small items, and to manufacture taper pins by hand.

.../(m)

(m) Douzieme Gauge · Similar to a vernier caliper and used widely in watch repairing. Often used on small work where a micrometer would be too clumsy.
(1 Douzieme = 0.0074")
(12 Douziemes = 1 lign 0.0888")

The Douzieme is an old French measurement still used in clocks and watches.

(h) Watch cleaning Machine - used for cleaning watches, and also useful in cleaning small parts of instruments, especially fine gearing
It consists of a rotating wire cage and four jars. The cage is lowered into each of the four jars in turn, and is rotated by means of a small electric motor
The first jar contains a cleaning fluid, the second and third jars contains a rinse, and the fourth jar contains a small heating element to dry cleaned items.
Providing the correct fluids are used, this is a quite and efficient method of cleaning small metal parts.

(o) Watchmakers' drills - are smaller than twist drills and have a straight space end. The sizes are metric, from 0.1 mm to 1.2 mm.

6. SPECIAL MATERIALS

These materials ensure cleanliness in instrument work. Some typical materials are:-

(a) Pegwood - used for cleaning holes and gear teeth
(b) Pith - for cleaning pivots, tweezers, etc.
(c) Rouge - for polishing small parts, usually pivots.
(d) Tissue Paper - for holding small parts, so preventing perspiration from the hand adhereing to such parts.
(e) Madapolin - a lint-free cloth for polishing parts.

TURNING

1. WATCHMAKER'S LATHE

This type of lathe is very similar in construction to a normal lathe. It is, however, much smaller and lighter. Furthermore, it has no gearing and cannot be used for screw cutting. It is belt driven from an electric motor.

(a) Component Parts

The lathe is made up of the following parts:-

(i) Bed - A rigid casting, its top ground to fine limits.

(ii) Head Stock - Detachable from the 'Bed'. Consists of a hollow spindle on bearings with a three-coned pulley drive and a screwed mandrel for holding collets.

(iii) Tail Stock - Detachable from the 'Bed' and similar to normal lathe. Can be fitted with either male or demale centres.

(iv) 3 Jaw-chuck - held in headstock by mandrel. It is self centering, and has reversible step jaws.

(v) 4 Jaw Chuck - held in headstock by mandrel. It has independently-operated reversible Jaws.

.../(v.i)

(vi) Split Wire Collets - held in headstock by mandrel. These are supplied in various sizes. They have three slots cut radially from a central hole. When a split wire collet is held in the headstock, the mandrel as it is screwed in closes the slots, and the edges of the hole grip the work. Providing the collet selected is of the correct size, a firm grip on the work is obtained. Sizes range from about 0.020" to 0.25" approx.

(vii) Step Collets - these are similar in construction to the previous collets but have no central hole. The front face is of a large diameter, and consists of receding concentric steps, by means of which discs or wheels may be held for turning.

(viii) Bell Chucks - these again are similar to the wire collets but are longer and hold larger diameter rods.

(ix) Screwed Bell chuck - this is a bell chuck without slots, but having adjustable screws to hold the work, which may be set eccentrically.

(x) Slide Rest and tool Post - similar to a normal lathe, but can be completely detached. Can be set for taper turning.

(xi) Tool Rest - This is supplied with two sizes of anvils and fits to the 'bed'. It is used for resting a tool on when turning by hand.

(xii) Tools - all necessary tools for the lathe are supplied. These include 'C' spanners, Allen Keys, tommy bars, etc.

(xiii) Lathe turning tools - these can be manufactured from $\frac{1}{4}$" square tool steel. Their shapes are similar to those used with a normal lathe.
For hand turning, a diamond pointed tool is normally used. This is called a "graver".

(b) Maintenance

At all times when not in use the lathe and its accessories should be clean and lightly oiled. Swarf is to be removed from all parts.
Bearings of the headstock should be oiled frequently with a thin oil. (e.g. Anti-freeze).
The following points should be carefully noted:-

(i) Don't allow bearings to become slack
(ii) Don't allow backlash in headstock
(iii) Don't put lathe tools on 'bed'
(iv) Don't put slide rest onto 'bed' with dirt or swarf between saddle and rest. It causes taper turning.
(v) Don't allow belting to become either too slack or too taut.
(vi) Don't allow rust to start.
(vii) Don't use a heavy file on any work, since this can cause play in headstock, and then accurate turning becomes impossible.

(c) Use of Watchmaker's Lathe

The lathe can be used for all jobs done on a normal lathe except screw cutting. In addition some types of watchmaker's lathes have gear-cutting attachments, used for cutting straight gears and pinions and also for light milling.

Drilling is carried out with the aid of a female centre in the tailstock, the drill being held by a carrier in the hand. This method gives a good "feel" of the drilling and enables small drills to be used with little fear of breakage. To centre drill a job for drilling the easiest and most convenient method is by using the diamond point hand graver.

Hand turning can easily be carried out. It requires a certain amount of practice, but is very quick when proficiency is attained. In using hand tools, they must never be allowed to stray too far above or below the centre of the job.

If the watchmaker's lathe is correctly looked after and used it is a very handy piece of equipment for small precision turning.

SOLDERING

1. SOFT SOLDERING

Soft soldering is a process for joining metal surfaces together by the application of low melting point alloys. Either a soldering iron or a spirit lamp may be used, according to the circumstances.

Since solder will only adhere to clean surfaces, fluxes are used to protect the surfaces from oxidisation and to help the solder to flow. For electrical connections, only resin or an approved paste flux is to be used. All corrosive fluxes must be avoided.

For other aircraft work, only soldering paste or soldering fluid is to be used, except for stainless steel, when phosphoric acid is employed. If fluid or acid is used as a flux the parts must be washed clean of all flux after soldering, as otherwise corrosion will set in.

Care must be taken to ensure that the finished job is not a "dry joint". Such a joint, though apparently satisfactory, will be broken by a good tug. This may be due to the following reasons:-

(a) Dirty Surfaces
(b) Iron too hot
(c) Iron not hot enough
(d) Dirty flux
(e) Wrong type of flux

2. HARD SOLDERING

This is used when a stronger joint is required than that produced by soft soldering. The parts to be joined are heated by a brazing or blow lamp, the flux being a paste of powdered borax and water applied before heating begins. The solders used may be brass spelter, silver solder or a mixture of both, but in all cases the solder must have a lower melting point than the job.

The job is prepared in the same way as for soft soldering.

3. SOLDERING OF CABLE ENDS

When soldering cable ends to electrical cables ensure that the correct flux is used. Also don't burn the cable insulation, and always clean off excess flux after soldering.

4. SOLDERING OF OXYGEN PIPELINES

Use a lamp where possible. It is easier and quicker than an iron. Only ONE flux can be used and that is "Killed Spirits" (33C/288). No other flux is permissible.

.../After

After soldering ensure the bore of pipeline is not blocked or restricted by solder. Then wash out with trioethelyne to ensure that pipe is free from grease and flux.

Finally blow through pipe with a blast of oxygen or clean dry air. Remember - on oxygen equipment, oil and grease can cause explosions.

PIPING

1. LOW PRESSURE ALUMINIUM PIPING (5/16" O.D. x 22 SWG).

This is used widely for instrument work, for oxygen equipment and on the Pitot and Static supply lines.

This piping is generally bent to the desired shape by hand. Care must be taken to ensure that no kinks or flats occur during bending.

2. LOW PRESSURE CONNECTIONS

These connections are supplied to join low pressure piping and to make it leak proof. The connections consist of a straight union, tee-union, or elbow union, into which the squared end of the pipe fits against a shoulder.

Over the end of the pipe is placed a union nut and a rubber ring. When the union nut is screwed onto the union it compresses the rubber ring over the pipe and so forms an airtight seal. After disconnection, a new rubber ring must be used when the low pressure union is screwed up again.

ELECTRICAL & INSTRUMENT SECTION

HENLOW DIVISION, R.A.F. TECHNICAL COLLEGE

THE GYROSCOPE

Instrument Precis No.9

Section 1. Moments of Inertia and Angular Momentum.

1. Suppose it is required to calculate the kinetic energy of a solid body, for example, a 1 ft. ruler rotating about one end, Figure 1, Although all parts of the ruler are rotating with the same angular velocity, W radians/second, the linear velocity, of the elements of the ruler increases with the radius at which the elements are placed, for

$V = r W$ where r is the radius of the element considered..... (1)

Now the kinetic energy of an element of the ruler is given by

Kinetic Energy = $1/2\ m\ V^2$ ft.lb. where m is the mass of the element in slugs and V its velocity in ft/second ..... (2)

Thus the kinetic energy of an element may be expressed as

Kinetic Energy = $1/2\ m\ V^2 = 1/2\ m\ r^2W^2$ ft.lb. ..... (3)

increasing with the square of the radius at which the elements are placed. To calculate the kinetic energy of the ruler as a whole, it will be necessary to sum the kinetic energy of each of the elements of the rule obtained by equation (3). This method of determining the kinetic energy will be used to determine other properties of rotating solid bodies, also. For the moment, kinetic energy is being taken as a convenient example of rotary motion.

2. Suppose the ruler is divided into the two equally-sized elements A and B, shown in Figure 2. If the mass of the whole ruler is m slugs, that of A and B will be $m/2$ slugs each. If the ruler is rotated about O at W radians per second, the kinetic energy of A will be given from equation 3, by

$$K.E._A = \tfrac{1}{2}\,\frac{m}{2}\,r_A^2\ W^2 \text{ ft.lb.}$$

and that of B by

$$K.E._B = \frac{\frac{1}{2}m}{2}\,r_B^2\ W^2 \text{ ft.lb.}$$

Since $r_A = \frac{1}{4}$ ft. and $r_B = \frac{3}{4}$ ft, the kinetic energy of the whole ruler will be given by

$$\text{Kinetic Energy} = \tfrac{1}{2}\,\frac{m}{2}\,(\tfrac{1}{4})^2W^2 + \tfrac{1}{2}\,\frac{m}{2}\,(\tfrac{3}{4})^2W^2 = \tfrac{1}{2}\,\frac{m}{2}\,W^2\ \frac{1}{4^2}\ (1+3^2)$$

$$= \tfrac{1}{4}\,m\,W^2\ \frac{5}{8} \text{ ft.lb.} = \frac{5}{32}\,m\,W^2 \text{ ft.lb.}$$

3. The ruler may be broken down into more and more equal-sized elements, the value of the total kinetic energy increasing slightly with the number of elements considered. Ultimately we may consider the ruler as consisting of an infinite number of infinitely small elements, each of mass d m slugs.

.../Consider

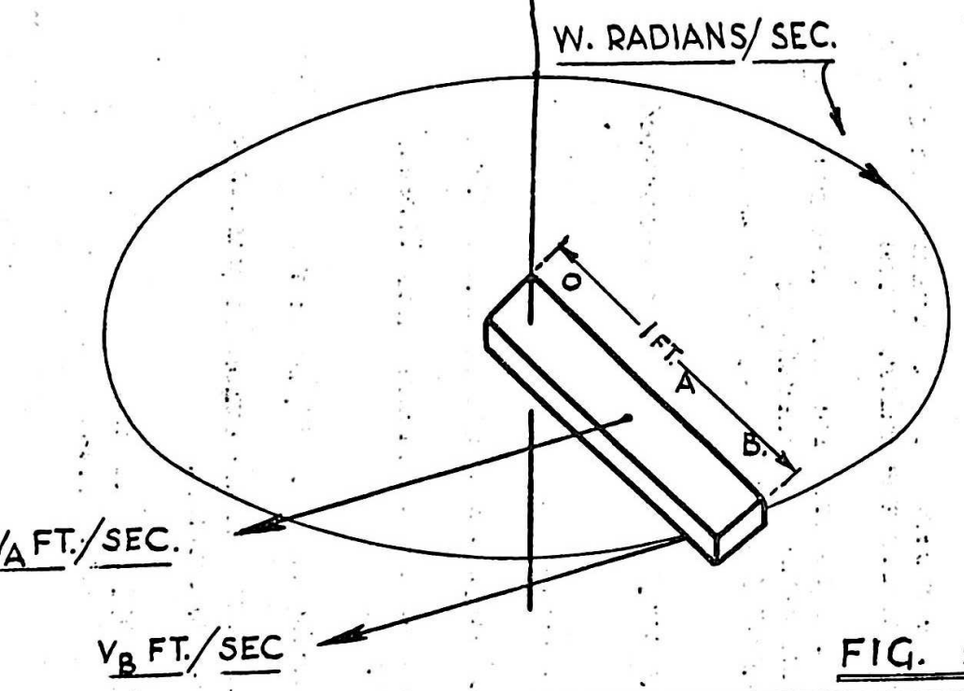


FIG. 1.

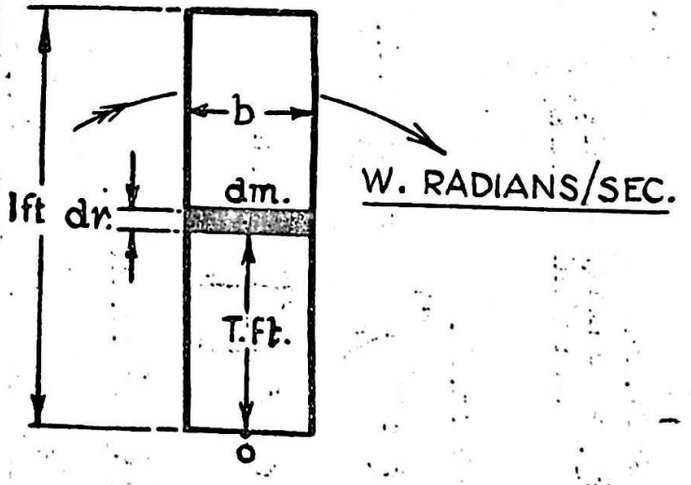


FIG. 3.

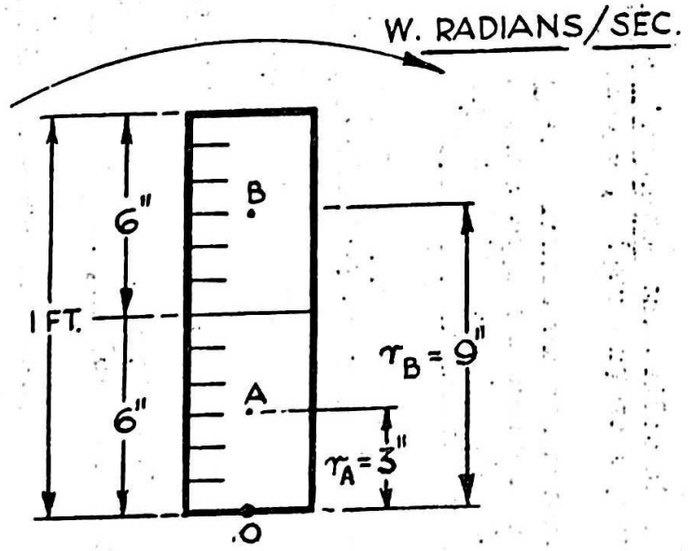


FIG. 2

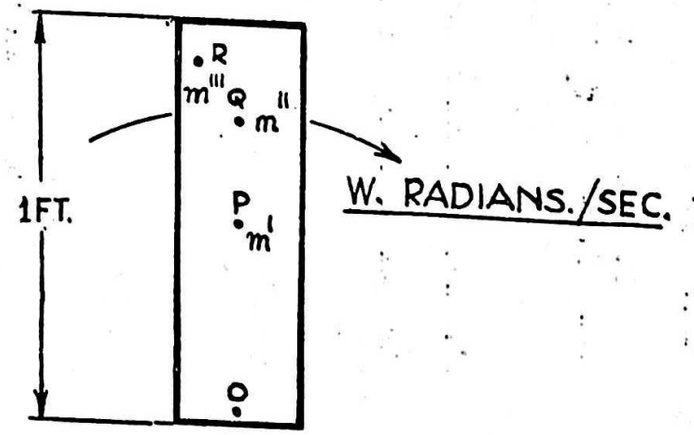


FIG. 4.

Consider one of these elements, distant r ft. from O, Figure 3. When the ruler rotates at W radians/second, the kinetic energy of this element is given by equation 3:-

K.E. of element = $\frac{1}{2}$. dm. $r^2 W^2$ ft.lb.

From Figure 3, dm = ρ x (b.d.r) where ρ = density of rule (mass/unit volume)

$\therefore$ K.E. of element = $\frac{1}{2} \rho\, b\, W^2 r^2\, dr$ ft.lb.

and the Kinetic energy of the ruler = $\frac{1}{2} \rho\, b\, W^2 \int_0^1 r^2\, dr$ ft.lb.

$$= \tfrac{1}{2} \rho\, b\, W^2 \left[\frac{r^3}{3}\right]_0^1 \text{ ft.lb.}$$

$$= \frac{1}{6} \rho\, b\, W^2 \text{ ft.lb.}$$

The mass m of the 1 ft. ruler = ρ b. slugs.
Thus the kinetic energy of the ruler = $\frac{1}{6}$ m W^2 ft.lb.

4. Consider the process that has been carried out in the last paragraph in another way. The ruler has been divided up into an infinite number of infinitely small elements each rotating about O with the same angular velocity of W radians/second. Call these P, Q, R etc. letting the mass of P be designated m^1, the mass of Q m'' that of R, m''' etc. Figure 4.

Then since the kinetic energy of the ruler = k.e. of P + k.e. of Q etc.

$$= \tfrac{1}{2} m^1 (OP)^2 W^2 + \tfrac{1}{2} m'' (OQ)^2 V^2 + \tfrac{1}{2} m''' (OR)^2 W^2$$

$$= \tfrac{1}{2} W^2 (m^1 (OP)^2 + m'' (OQ)^2 + m''' (OR)^2 + \ldots\ldots\ldots)$$

Kinetic energy of the ruler = $\frac{1}{2} I W^2$ f . lb. .....(4)

$I = m^1 (OP)^2 + m'' (OQ)^2 + m''' (O R)^2 + \ldots\ldots\ldots$ etc.....(5)

I is called the moment of inertia of the ruler. It is measured in slug-ft^2 and, from paragraph 3, equals $\frac{(m)}{(3)}$ slug-ft. for the ruler. The expression for the kinetic energy of the ruler is true for all other rotating bodies provided the appropriate value of the moment of inertia is calculated. Values of I for geometrically-shaped bodies may be found in books of mathematical tables.

5. The moment of inertia of a particle (a body with its mass concentrated at a point) is given from equation 5 by

$$I = m k^2 \text{ slug-ft}^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

where m is the mass of the particle in slugs and k its radius in ft.

6. Figure 5 shows a force of F lb. applied to the particle. Its linear acceleration resulting from F will be given by

F = m.a. lb. where a = linear acceleration in ft/second^2.

Now $a = k \alpha$ ft/sec^2, where α = angular acceleration of particle in radians/second^2.

Therefore $F = m.k\alpha$ lb, or the torque applied to the particle
$T = Fxk$ lb.ft. $= m k^2 \alpha = I \alpha$ lb.ft..... (7)

/For the

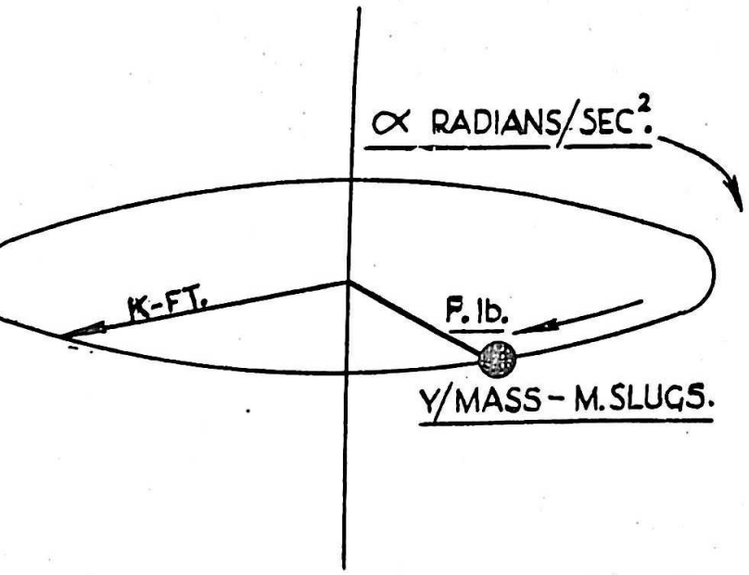


Fig. 5.

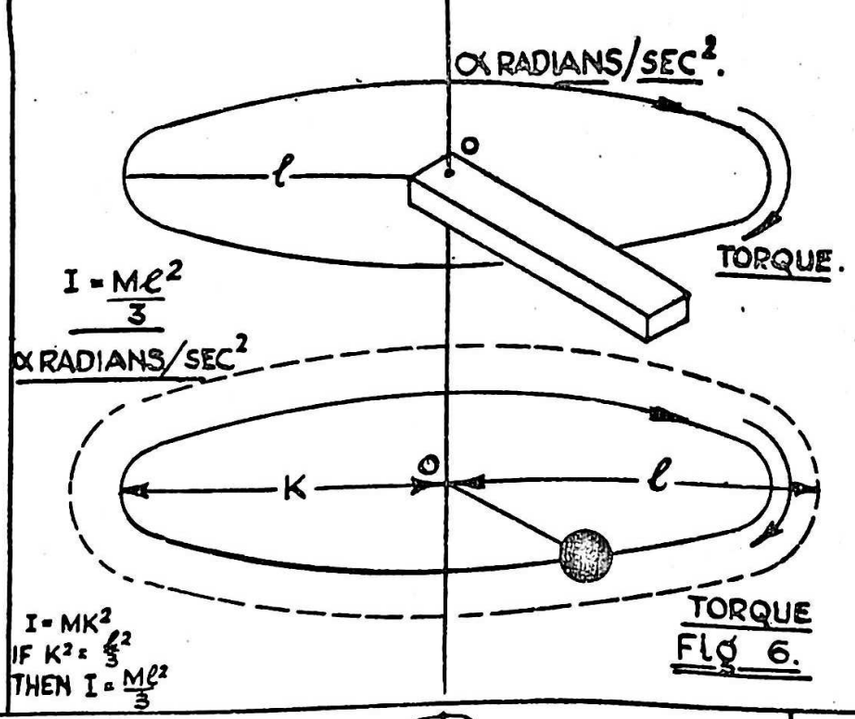
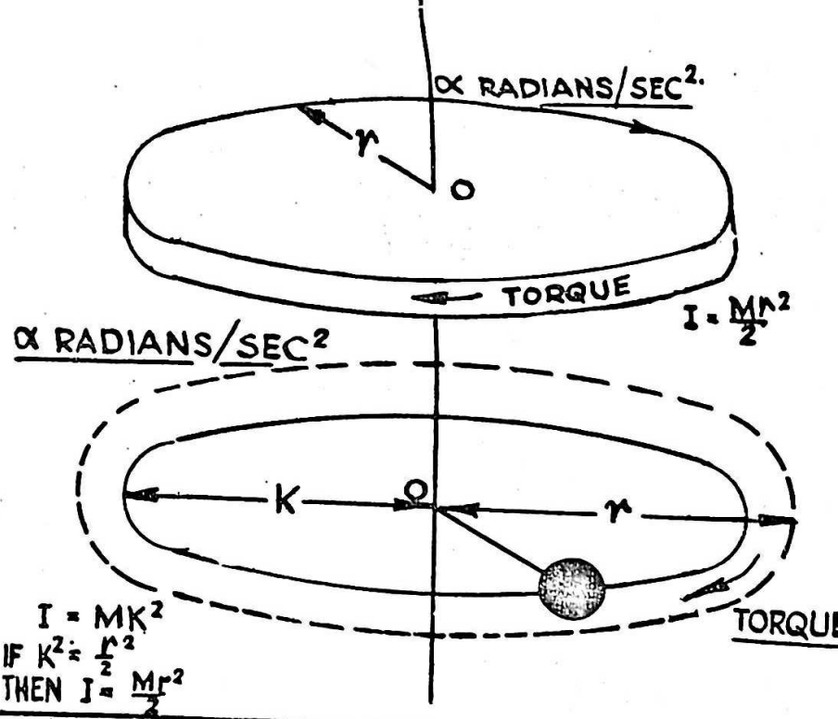
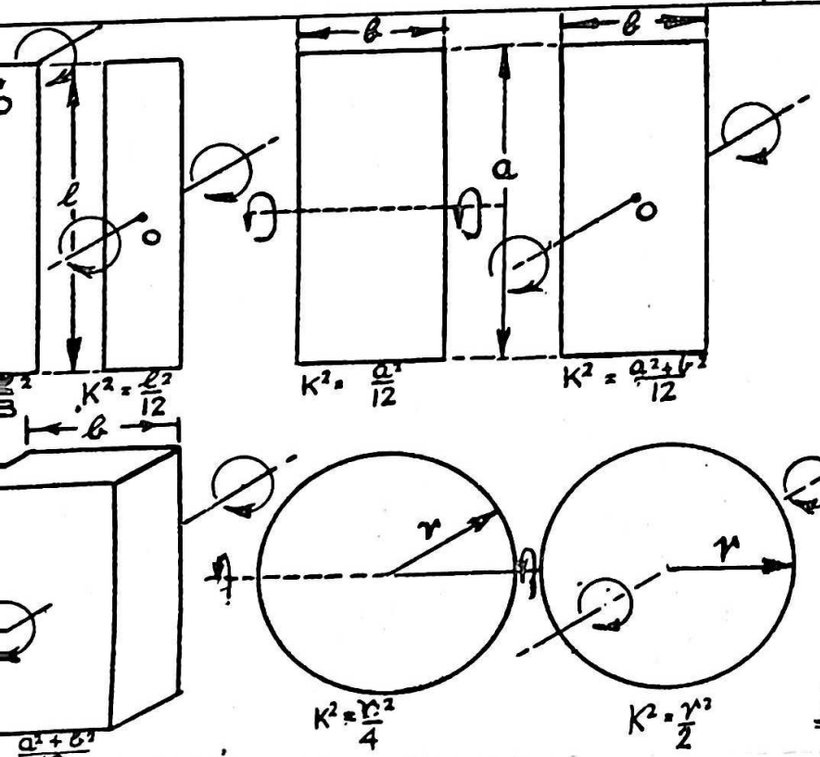


Fig 6.





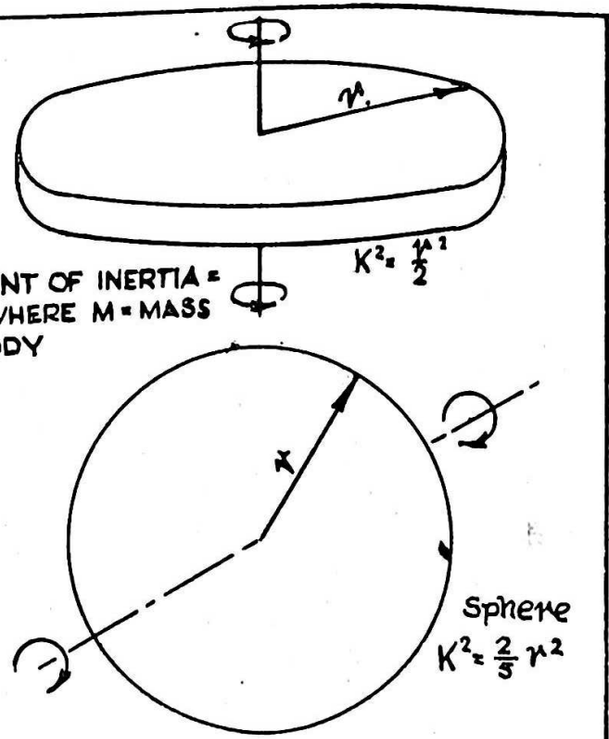


Fig 7.

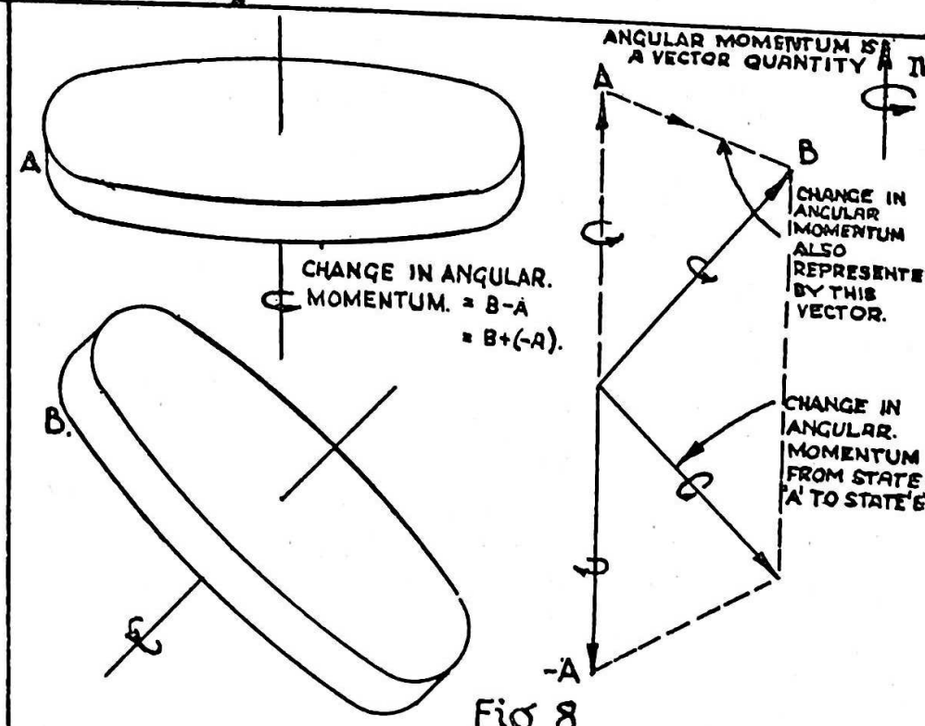

A
CHANGE IN ANGULAR. MOMENTUM. = B-A = B+(-A).
B.
ANGULAR MOMENTUM IS A VECTOR QUANTITY
A
B
CHANGE IN ANGULAR MOMENTUM ALSO REPRESENTED BY THIS VECTOR.
CHANGE IN ANGULAR. MOMENTUM FROM STATE 'A' TO STATE 'B'
-A

Fig 8

For the particle, then, the applied torque T produced an angular acceleration α, given by $T = I\alpha$. This expression is true for all rotating bodies, provided the appropriate value of moment of inertia is calculated and used.

7. If we wish to find the angular acceleration of <u>any body</u> free to rotate resulting from the application of a torque, we represent the rotating body by a rotating particle of the some mass as the body at such a distance from its axis of gyration that its moment of inertia is equal to that of the body. Then if the same torque is applied to the particle as was to the body, the resulting angular acceleration will be the same. We call this equivalent radius at which the particle rotates, the <u>radius of gyration</u> and denote it by "k", Figure 6.

Thus the moment of inertia of a body is equal to the product of its mass and the square of the radius of gyration (equation 6) where the radius of gyration is the radius at which a particle of the same mass of the body must be placed in order that this particle, when rotating, may present the same appearance to applied phenomena as the body rotating at the same speed. Values of the radius of gyration for some geometrically-shaped bodies are given in Figure 7.

8. Angular Acceleration = The rate of change of angular velocity.
Thus from equation 7, the torque on a body is equal to
Ix (Rate of change of angular velocity with time).
Now I for a body is independent of time, so we may write
Applied Torque = Rate of change of (IxW).

IxW is called the angular momentum of a body.
Thus <u>Applied Torque</u> = <u>The Rate of change of angular momentum of a body</u> .....(8)

9. Notice that if no torque is applied to a body, or system of bodies, there can be no change of angular momentum. This principle is known as the <u>Conservation of Angular Momentum</u>. Angular Momentum is a vector quantity and <u>a change in direction of a rotating body constitutes a change in angular momentum.</u> Consequently a freely rotating body will not change its direction unless acted upon by an external torque, and we say that the rotating body is stable. Should a torque be applied to a freely rotating body, deflecting its axis through an angle, its angular momentum is changed, even though the <u>magnitude</u> of its angular velocity and its moment of inertia remain unchanged. These effects are illustrated in Figure 8.

Section 2. GYROSCOPIC THEORY

10. Consider the axis of a rotating body being deflected by a small angle θ. Although the magnitude of angular velocity and moment of inertia remain unaltered, angular momentum will be changed, as has been shown in paragraph 9. Let us calculate the amount by which it is changed. The rotating body is shown in figure 9.

If θ is small, the change in angular momentum = $IW\theta$ slug.ft^2/sec.
If the change takes place in time t,
The Rate of change of Angular Momentum = $\frac{IW\theta}{t}$ slug.ft^2/sec.^{2}

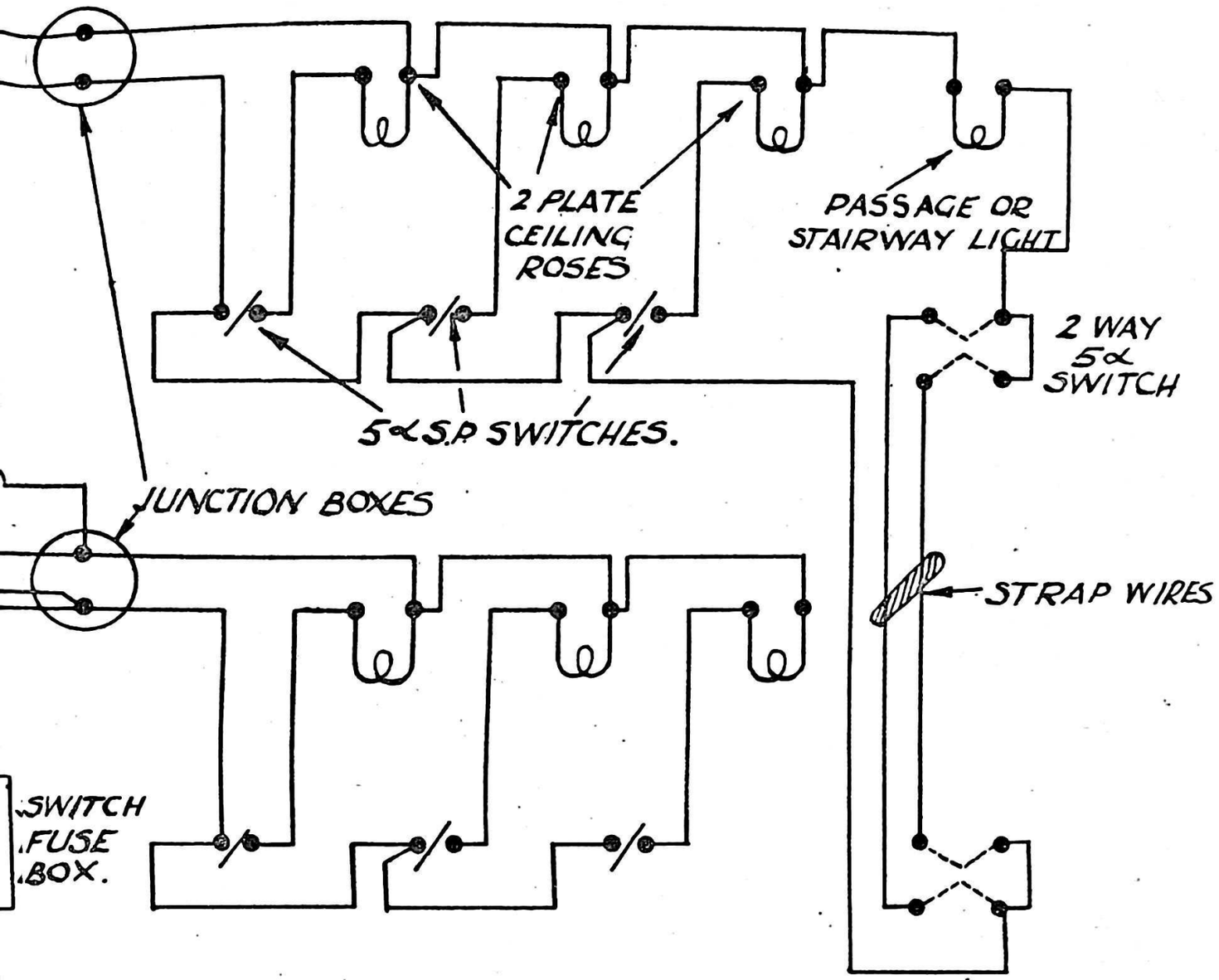
But θ/t is the rate of deflection of the body's axis, defined as w. The Rate of change of Angular Momentum is equal to the torque applied to the rotating body to bring about that change (equation 8).

Hence Applied Torque producing deflection = IWw slug.ft^2/sec^2
= IWw lb.ft .....(9)

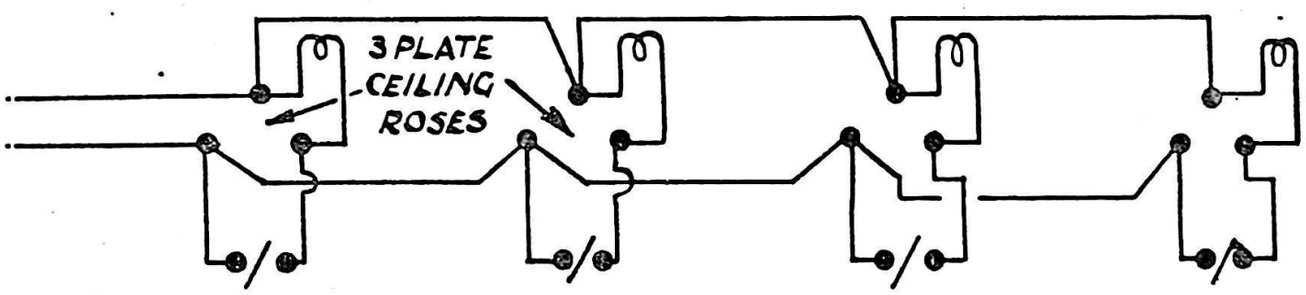
.../The direction

HOUSE WIRING AND SWITCHING SYSTEMS

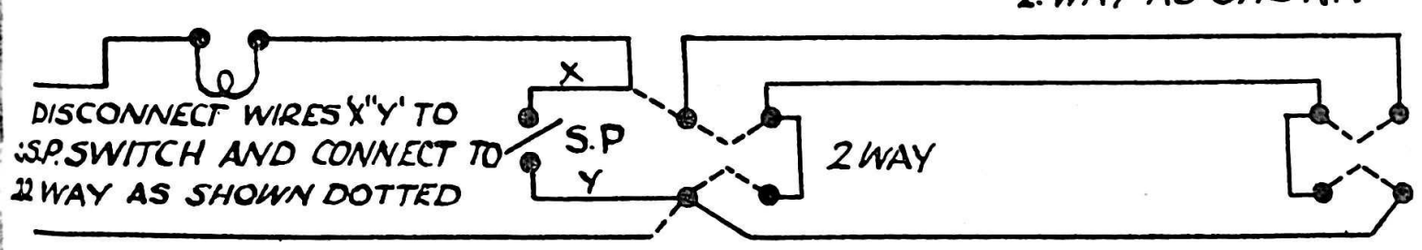
"LOOPING IN" METHODS.



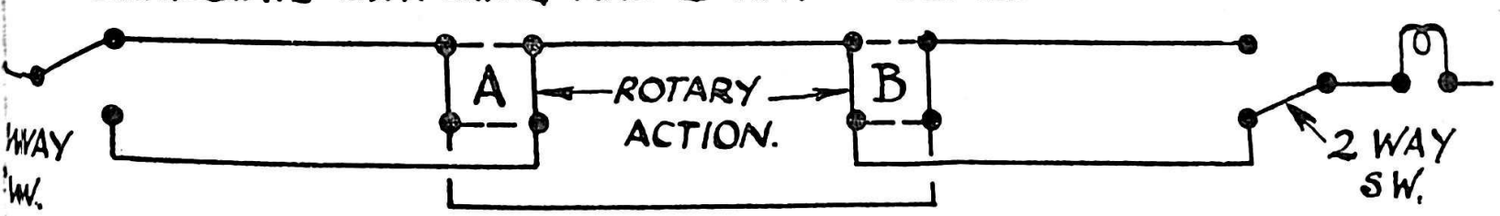
USING 3 PLATE CEILING ROSES AND TWIN CABLE



ING EXISTING LAMP WIRES FOR 2 WAY SWITCHING REMOVE S.P. SW. FIT 2. WAY AS SHOWN

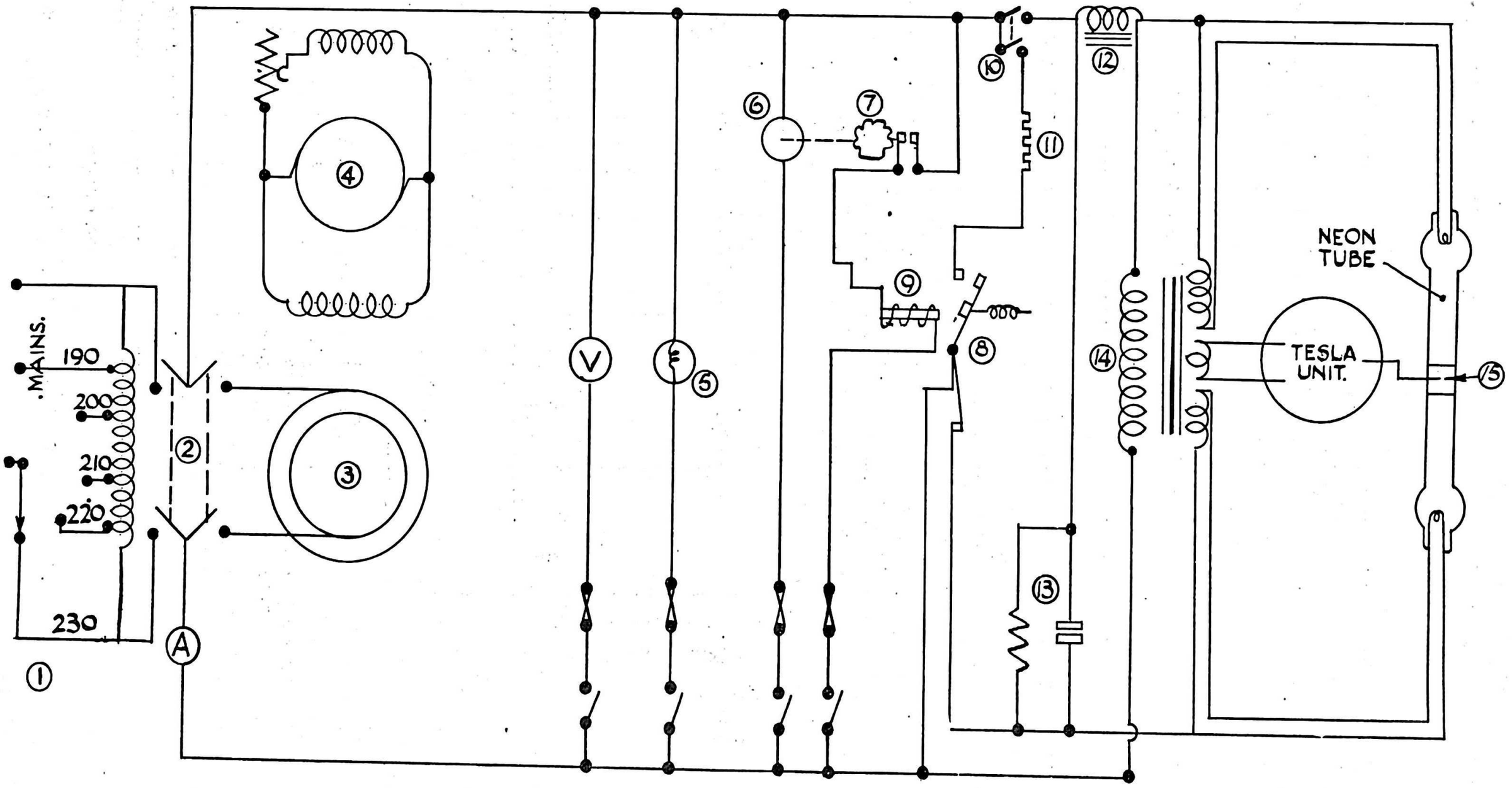


INTERMEDIATE SWITCHING AND 2 WAY COMBINED.



LIGHT WILL BURN WHEN ANY ONE OF THE 4 SWITCHES ARE OPERATED.
IT CAN ALSO BE SWITCHED "OFF" FROM ANY POSITION

3 K.W. MOBILE LANDMARK BEACON



1. AUTO TRANSFORMER
2. CHANGE OVER MAIN SWITCH
3 ALTERNATOR.
4. EXCITER.
5. CARBON FIL. LAMP
6. SQUIRREL CAGE MOTOR
7 LETTER DISC.
8 CONTRACTOR.
9 MAGNET
10. SELECTOR SWITCH
11. 85Ω SUBST. RESIST.
12. CHOKE.
13. 80MFD CONDENSE
14 TRANSFORMER
15. IONISING BAND.

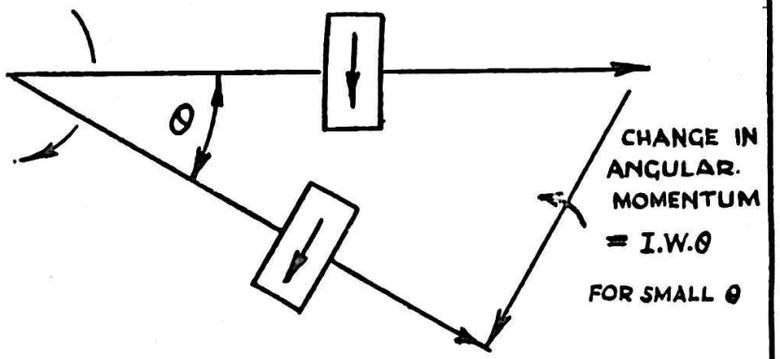


Fig. 9.

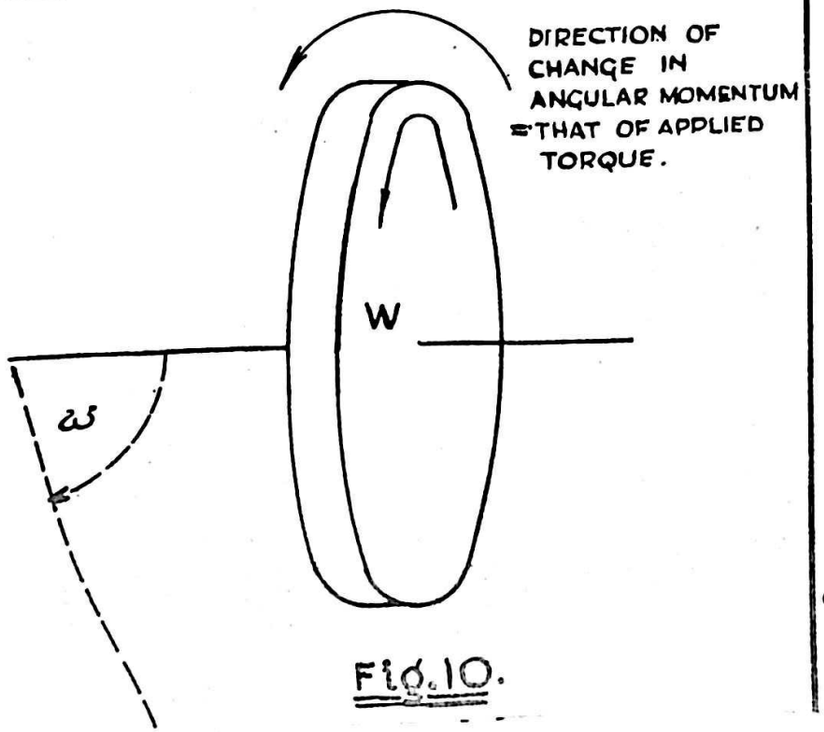
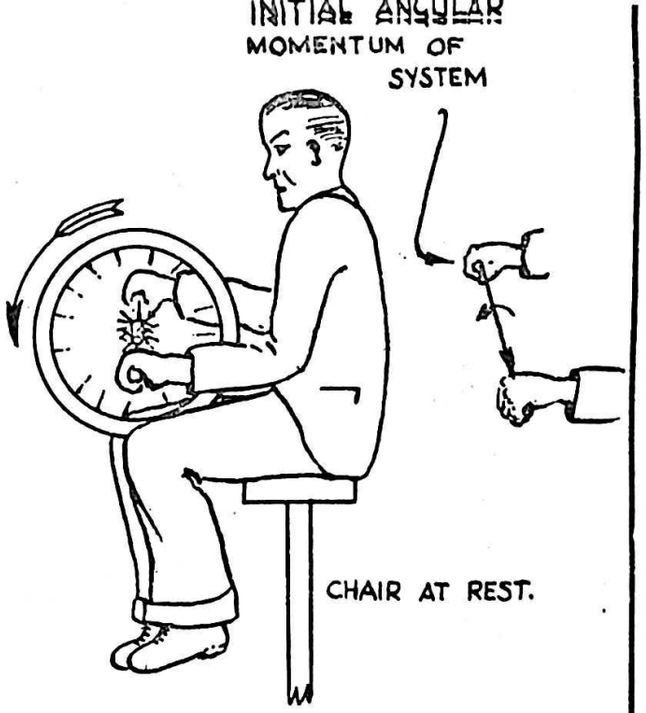


Fig. 10.



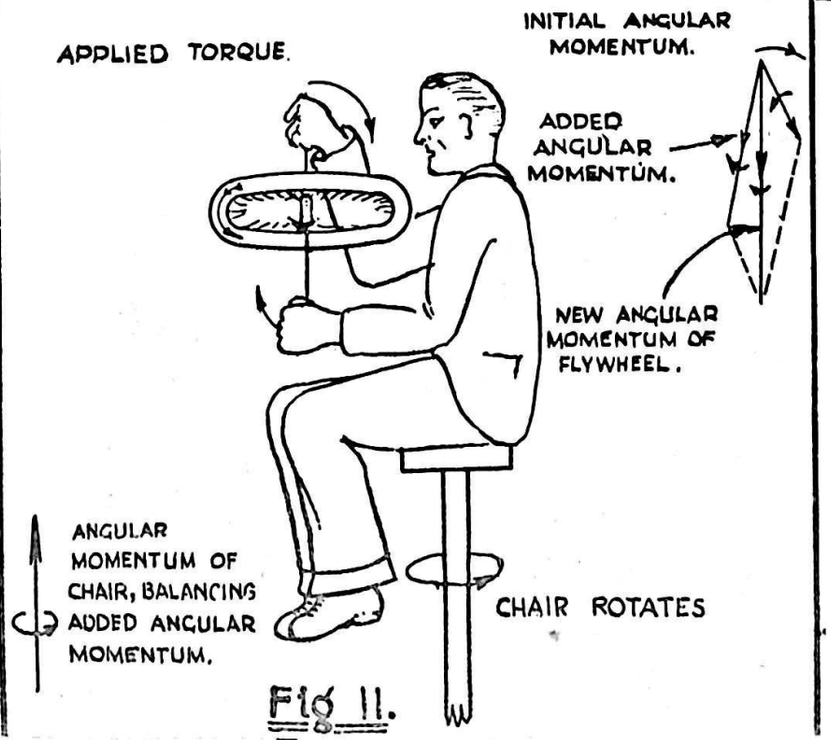


Fig 11.

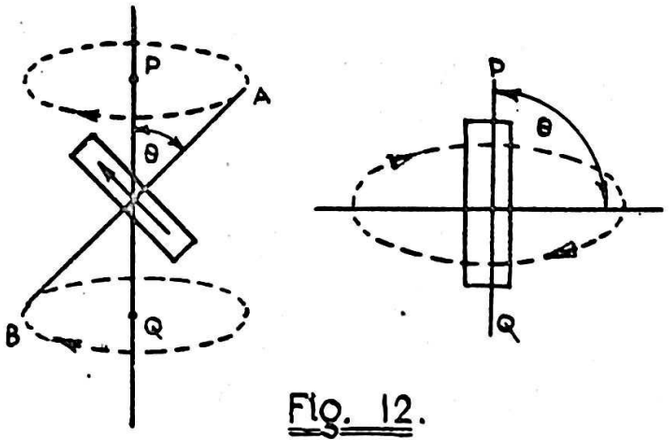
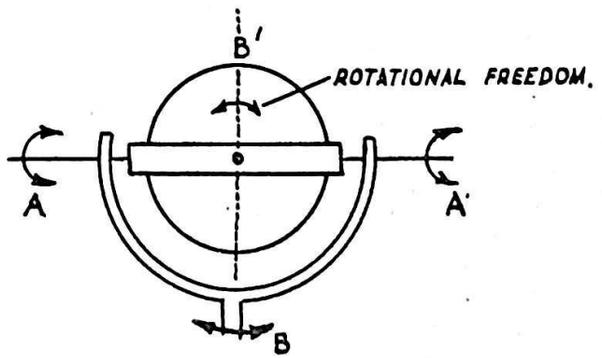


Fig. 12.



ROTATIONAL FREEDOM
FREEDOM ABOUT A-A' . FREEDOM ABOUT B-B'

Fig 13

11. The direction of the change in angular momentum is shown in Figures 9 and 10. It is seen to be in a different direction from that in which the axis deflects. This apparent contradiction to the laws of Applied Mechanics can be understood if it is realised that the particles of the rotating body are not merely being deflected with the axis, they are also rotating about the axis. The torque applied produces a net resultant motion in its own direction.

12. The direction of applied torque and resulting gyroscopic deflection may also be studied by reference to the rotating chair illustrated in Figure 11. Application of a torque to the rotating wheel brings about rotation of the originally stationary chair, causing deflection to the axis of the rotating wheel in accordance with figure 9 and paragraph 11.

13. The deflection of the axis of the rotating body on application of a torque is termed gyroscopic precession. The latter term is rigidly defined as follows.

"If the axis of a rotating body AB (Figure 12) makes an angle with some fixed direction PQ, and AB performs a conical movement about PQ, the rotating body is said to precess about PQ."

Thus precession is brought about on the application of a torque to a rotating body, the precession taking place in a different plane from that in which the torque is applied. Notice that precession is motion with uniform angular velocity (Equation 9), the velocity which has been called w radians/sec.

14. A gyroscope is defined as a solid of revolution capable of rotation, with one or more degrees of freedom at right angles to the plane of rotation and this definition is illustrated in Figure 13. It should be noted that this definition does not only apply to small rotating parts of aircraft instruments, indeed a practical example of precession resulting from the application of gyroscope torque is that of turning a corner on a bicycle, Figure 14. Notice that according to equation 9, the faster the angular velocity of the cycle, the slower the turn, if the applied torque is constant. Other applications include the torque produced on a car axle by one driving wheel falling into a pot-hole; a similar torque on a railway engine axle when one wheel falls slightly over a bad rail-joint; the gyroscope action of an aircraft propellor, or the precession of a gyro-compass.

15. The stability of a revolving gyroscope is an effect arising from the Conservation of Angular Momentum principle, described in paragraph 9. When no external torque is applied to the gyroscope it will remain pointing in the same direction in space, but if a deflection of a given amount is required in a given time, equation 9 shows that the torque to produce the deflection is inversely proportional to the gyroscopes angular momentum. Thus a greater torque must be applied to a rapidly rotating gyroscope of large mass to achieve the same rate of precession as that obtained on a small, slowly rotating gyroscope.

16. In paragraphs 9 and 10, the direction of gyroscopic precession is shown by reference to angular momentum vectors. Sperry derived a simple rule of thumb to give this direction.

"Imagine the applied torque as if caused by a force acting at a point on the rim of the gyroscope rotor, Figure 15. Now carry this point round the rotor 90° in the direction of rotation, and that will be the point at which the force is apparently taking effect, moving that part of the rotor rim in the same direction as the disturbing force."

17. If the precession of a gyroscope is retarded by a force, such as friction, more work is required to overcome the force. The rate of precession is not reduced but the axis about which the torque producing the precession is applied moves through an angle in the direction of the

.../torque

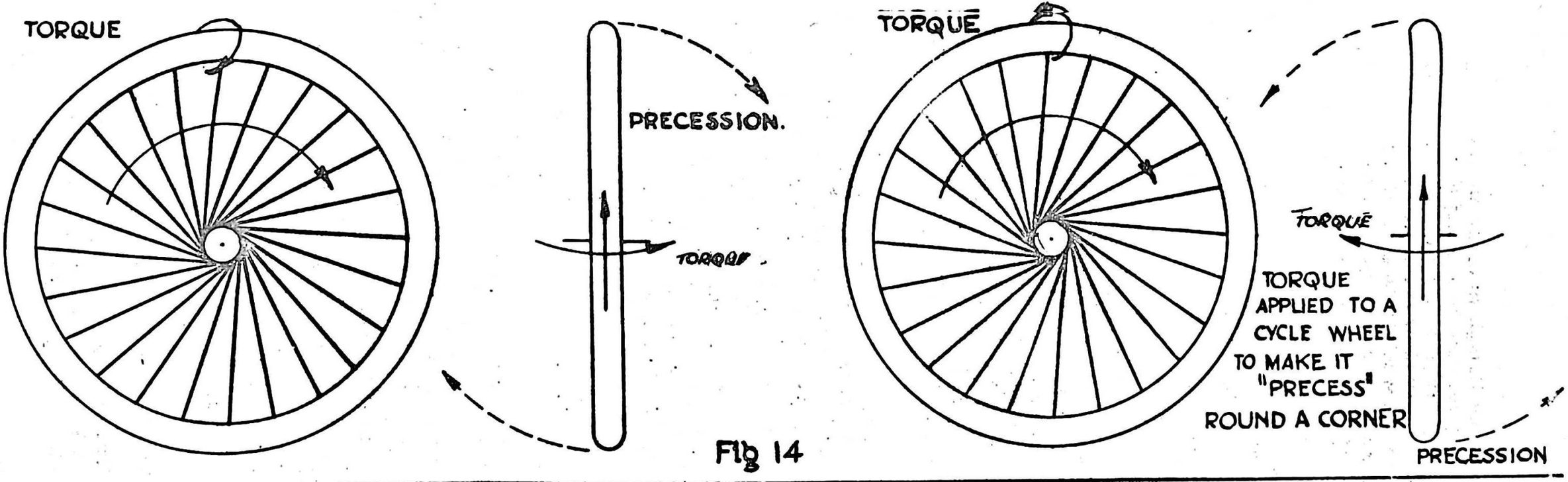


Fig 14

SPERRY'S RULE

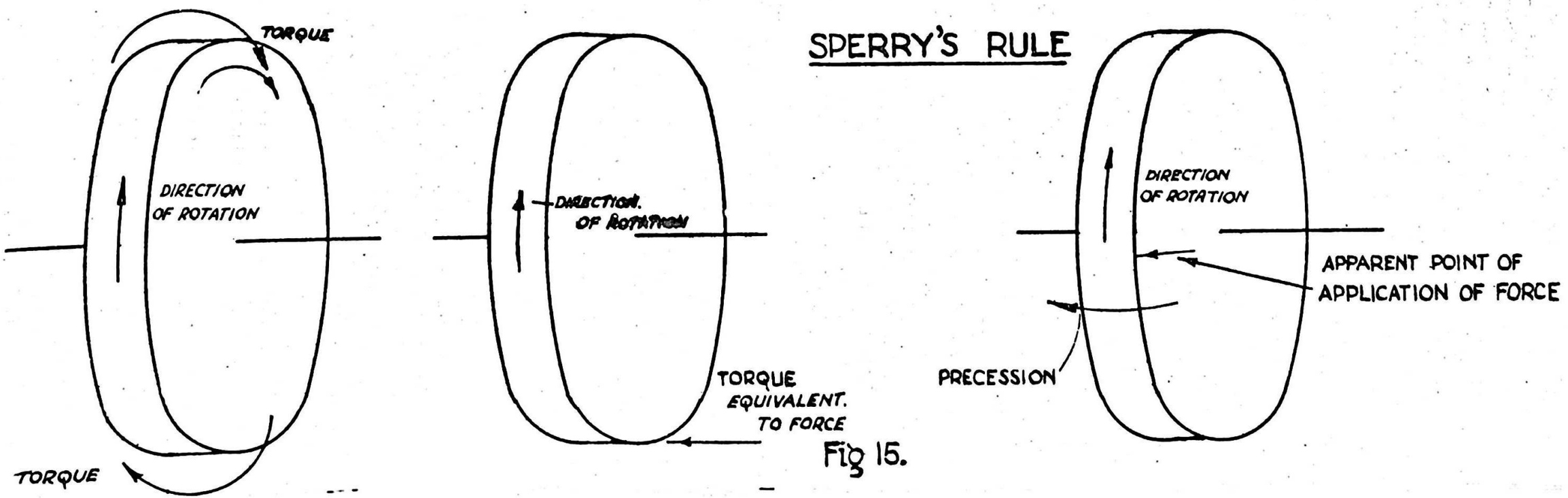


Fig 15.

torque; for work is doen when a torque moves through an angle in its own direction. Similarly if the rate of precession is increased by a force and less work is required from the gyroscope to maintain a given kinetic energy of precession, then the torque will be moved through an angle in the opposite direction to that in which it is applied and thus the force tending to hurry precession does work on the applied torque. In the extreme case, either of the two phenomena described can cause the gyroscope to topple.

Section 3. APPLICATION OF THE GYROSCOPE IN AIRCRAFT.

18. Definitions

Axis of spin and plane of spin. Illustrated in Figure 16.

The axis of spin of a gyroscope is the axis lying along the length of the gyroscope axle. The plane of spin is a plane perpendicular to the axis of spin containing the gyroscope rotor.

Space-bound gyroscope. Illustrated in Figure 17.

A space-bound gyroscope is one that maintains its position relative to some object fixed in space, thus any well-balanced gyroscope is space-bound. A space-bound gyroscope on the earths surface will appear to an observor on the earth to be precessing, as the earth rotates beneath it. The gyroscope will also appear to precess as it is moved about the earth's surface. The apparent rotation of a space-bound gyroscope as the earth rotates is termed Apparent Precession. Rate of apparent precession will depend on the attitude and latitude of the gyroscope.

If a gyroscope is positioned at the North Pole with its plane of spin perpendicular to the earth's surface a, in Figure 18A, it will appear to an observer on the earth to be precessing with the earth's angular velocity in the opposite direction to that in which the earth rotates. At the point X on the earth's surface, the component of the earth's angular velocity about an axis perpendicular to the earth's surface is $\bar{w}$ Sin θ where $\bar{w}$ is the angular velocity of the earth and θ is the latitude of X. Thus gyroscope b will apparently precess at w Sin θ, whereas gyroscope c will apparently precess at $\bar{w}$ Cos θ about the axis indicated in Figure 18A. The resolution of the earth's angular velocity into the components $\bar{w}$ Sin θ and $\bar{w}$ Cos θ is shown in Figure 18B.

The angular velocity of rotation of the earth is 2 π radians every 24 hours which is 15 degrees per hour.

Earth-bound gyroscopes. Illustrated in Figure 17.

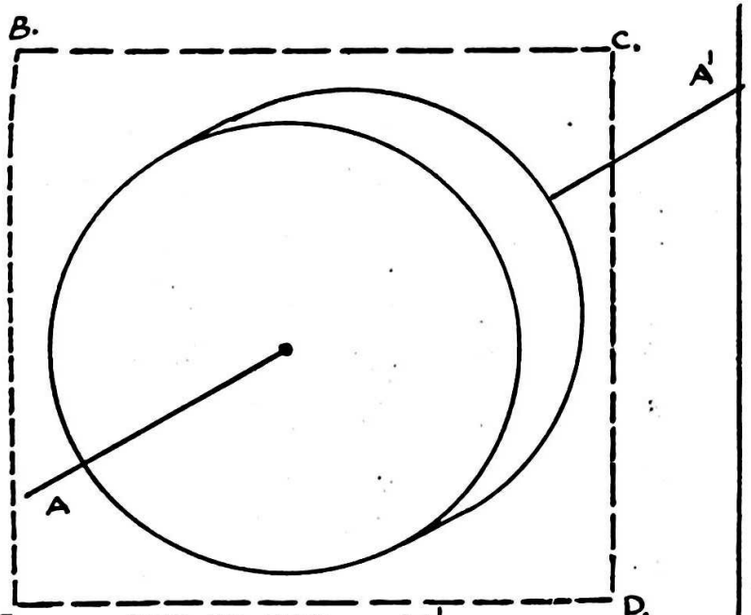
An earth-bound gyroscope is one that does not exhibit apparent precession on the surface of the earth. In order that it may appear to remain stationary, it must actually precess at the same rate as the earth, and so that this may be achieved, weights are applied to the rings to produce the necessary precession. As the rate of apparent precession varies over the earth's surface, a gyroscope that is earth-bound for one latitude will not be so for another.

Tied Gyroscopes. A tied gyroscope has freedom in three planes but is controlled by some external force.

Free Gyroscopes, are neither earth-bound, tied or space-bound.

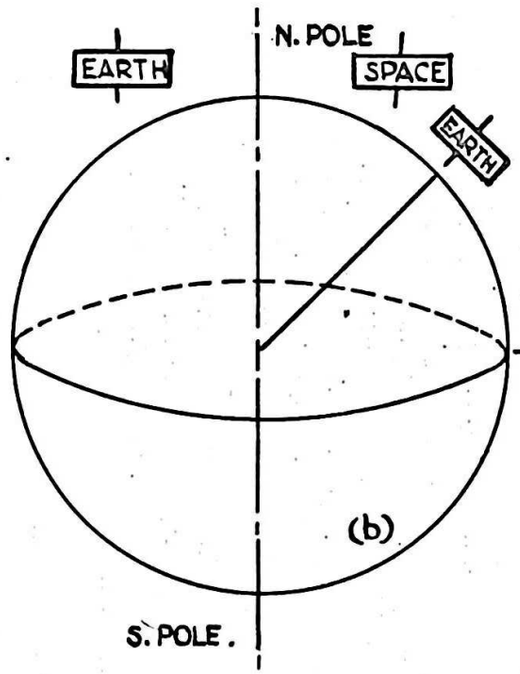
19. The Direction Indicator. This instrument possess a gyroscope rotor which is tied to the outer gimbal ring. The latter, (on which the scale is attached) is fixed in the aircraft. The gyroscope rotor, though

.../free to

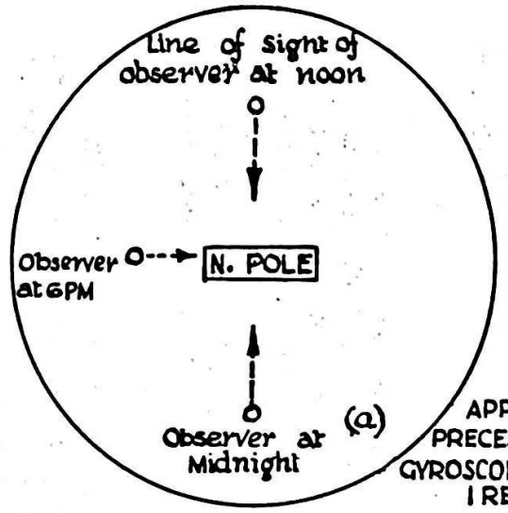


AXIS OF SPIN = AA'
PLANE OF SPIN = PLANE BCDE

Fig 16.



EARTH BOUND AND SPACE BOUND GYROSCOPES



APPARENT PRECESSION OF GYROSCOPE 1 REV/24 HRS

Fig 17.

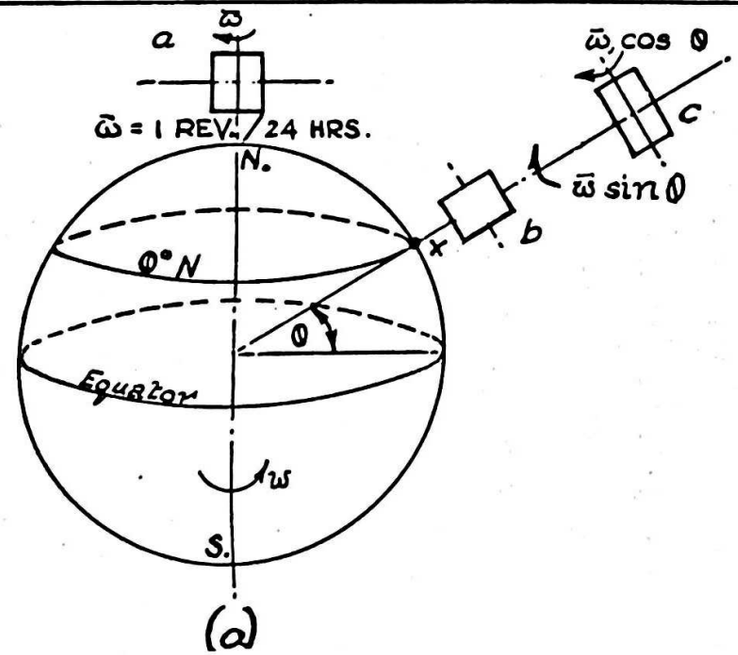
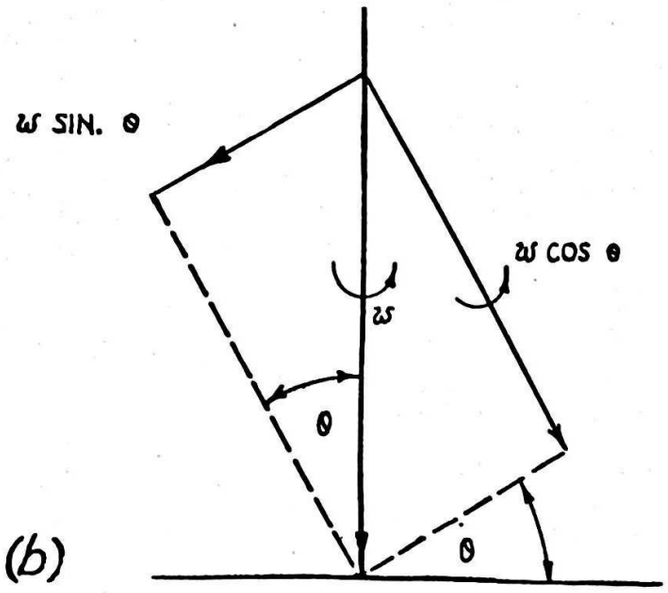


Fig 18.



free to rotate within the outer ring, will always set itself with its plane of spin parallel to the inner ring.

Consider Figure 19. The air impinging on the rotor and rotating it is shown by the vector V. When the gyroscope is deflected away from the inner ring, a component of V continues to rotate the rotor, but another component of V, marked V_b applies a force to the gyroscope rotor. Carrying this force round the rotor 90° in the direction of rotation in accordance with Sperry's rule (paragraph 7), it is seen that the rotor will be restored to a position parallel to the inner ring, when the component V_b will no longer exist.

If the aircraft flies straight and level, the plane of spin is always perpendicular to the earth's surface, so the direction indicator will exhibit apparent precession at the rate of 15 Sin θ degrees/hour where θ is the latitude angle. This phenomenon is known as drift due to the earth's rotation and can be compensated for at a particular latitude by applying a constant torque of the correct magnitude to the gyroscope rotor. For all practical purposes, it should not be necessary to compensate for this factor unless the instrument is transferred over more than 60° of latitude on the earth's surface.

Drift will also be caused by mechanical disturbance (friction, etc.) applying a torque to the rotor. These may be compensated for at all latitudes.

20. The Artificial Horizon. This instrument possesses a gyroscope whose plane of spin is maintained parallel to the earth's surface and hence a bar connected to the rotor plane will represent the position of the horizon relative to the particular flying attitude of the aircraft. The plane of spin is maintained parallel to the earth's surface by a gravity-actuated device. Air, having rotated the gyroscope, emerges from the instrument through four ports, P, in the base (Figure 20). The ports are normally half covered by pendulous vanes, but should the axis of the gyroscope deflect from the vertical (with respect to the earth), the vanes are so arranged that one will open its port, whilst the opposite vane keeps its port fully closed. The reaction from the rush of air through the -opened port causes the gyroscope to precess until its axis is again vertical. Then the outflow from each of the ports is the same and there is no net reaction to produce further precession.

21. Rate (or restrained) Gyroscopes (e.g. Turn Indicator; Mark IX Autopilot)

(i) The aircraft turns about the vertical axis AA' at $\bar{w}$ radians/second (Figure 21a)

(ii) The inertia of the gyroscope causes it to remain in its original position, so a force F acts upon it.

(iii) F causes the gyroscope to precess as though an apparent force G acts. As the gyroscope precesses, the pointer is deflected and the Spring S extended.

(iv) The extended spring applies a force F' back on to the gyroscope. (Figure 21b). Deflection of the pointer and extension of the spring occurs until F = F'.

(v) F' precesses the gyroscope as though an apparent force G' acted. This causes the gyroscope to rotate about AA' with the aircraft.

(vi) Let T be the applied torque resulting from F, and T' that resulting from F'. Then from (iv) above, T = T'.

(vii) Now T = I W w where I is the moment of inertia of the gyroscope and is its rotational angular velocity.

(viii) But since T' = T ; T' = I W $\bar{w}$, i.e. the angular velocity of precession of the gyroscope arising from T' is at the rate of turn of the aircraft about AA'.

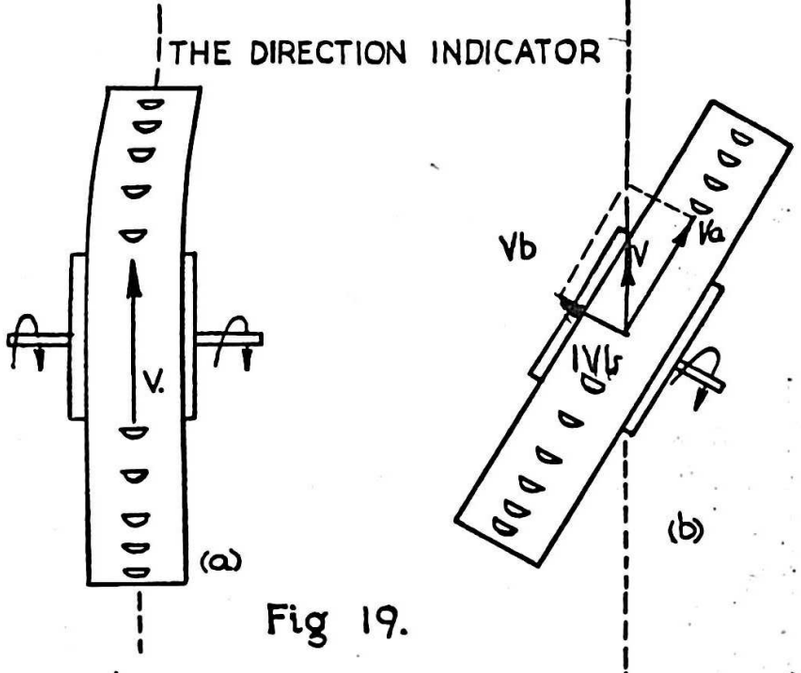
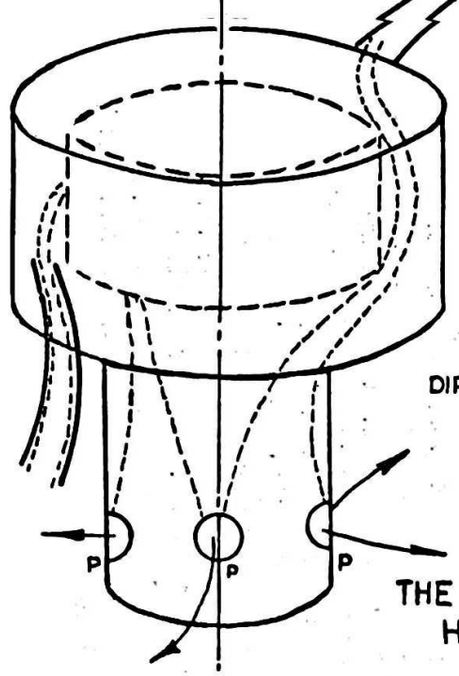


Fig 19.



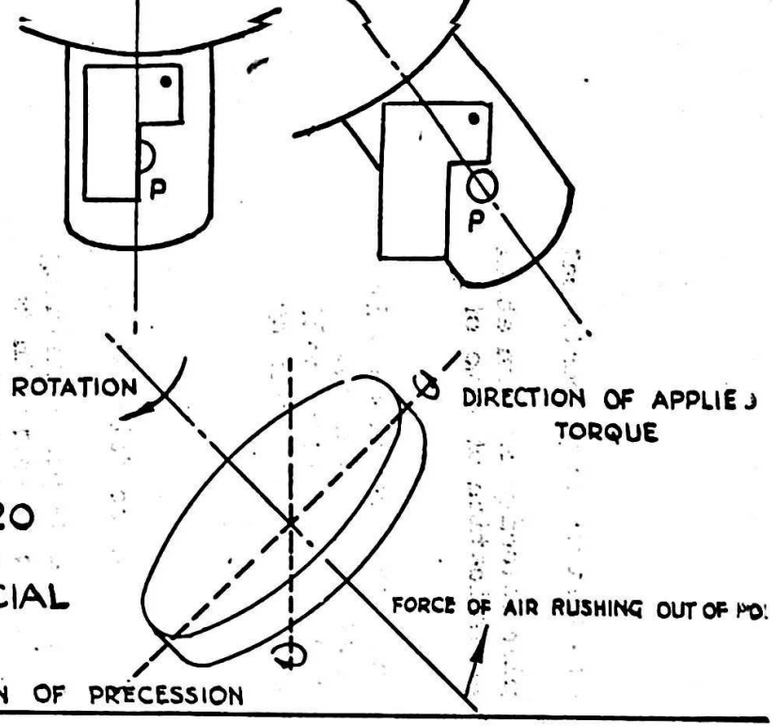
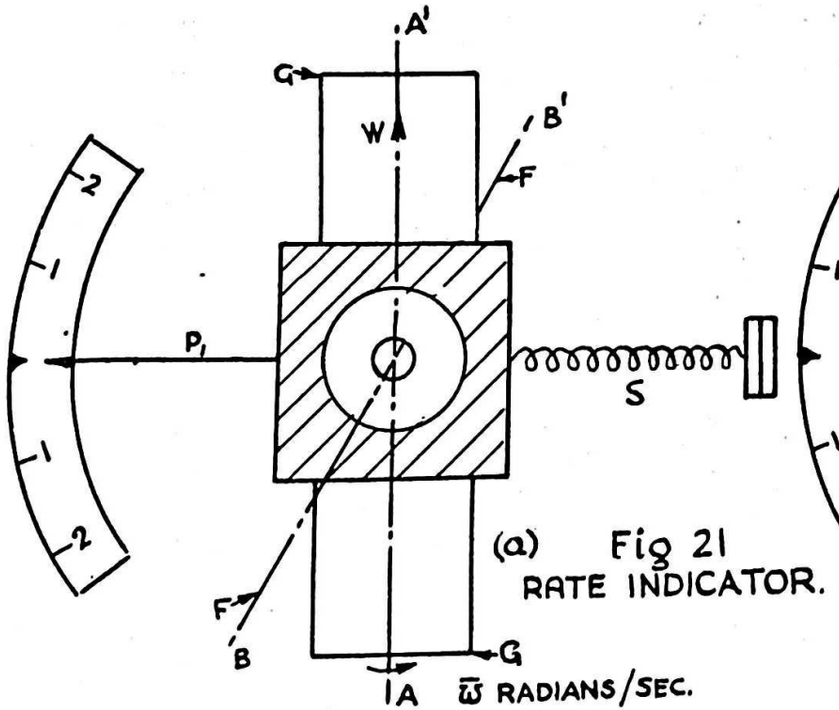
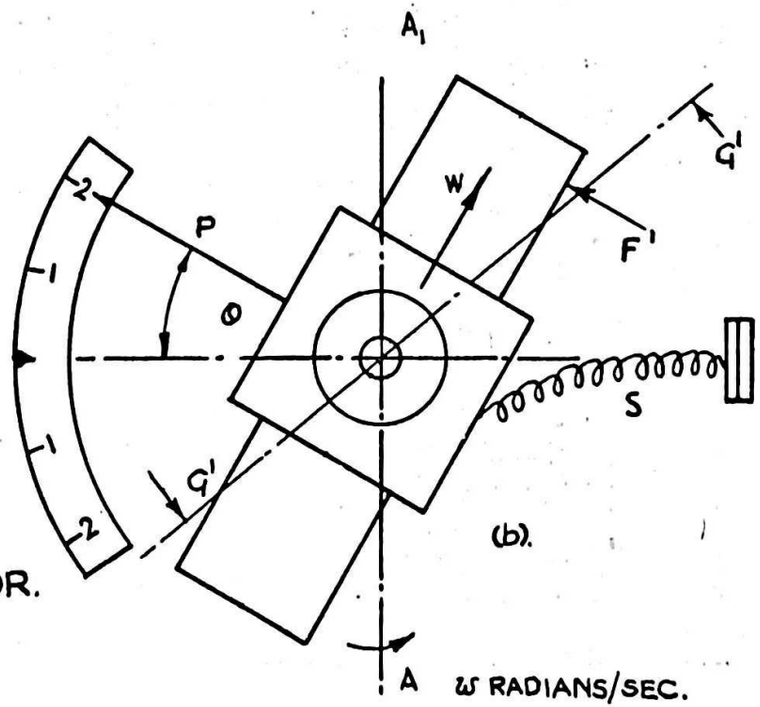


Fig 20

THE ARTIFICIAL HORIZON



(a) Fig 21
RATE INDICATOR.



(b).

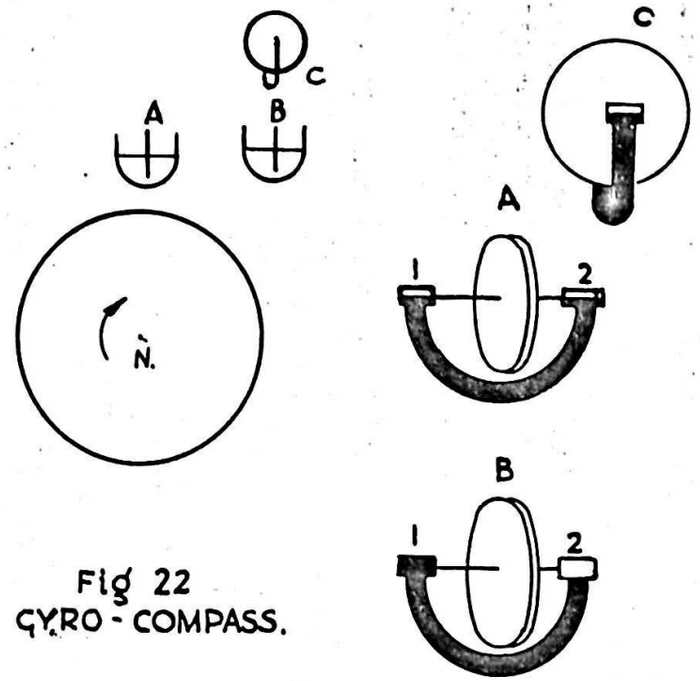


Fig 22
GYRO - COMPASS.

(ix) If the spring is constructed so that T' is proportional to the pointer deflection θ, θ is proportional to the angular velocity of turn about AA', i.e. the pointer gives an indication of rate of turn.

(x) From (viii) since $T' = I W \bar{w}$ and from (ix) since θ is proportional to the angular velocity of turn, the more rapidly the gyroscope rotates, the greater will be the deflection of the pointer for a given rate of turn.

22. The Gyro Compass

The operation of the Sperry Gyro-Compass is as follows:

Mounted on the axle of the gyroscope is a U-tube containing mercury, running underneath the gyroscope and culminating in two cups, 1 and 2, Figure 22, this tube forming the inner ring of the gyroscope. At the instant shown at A, no torque is applied to the gyroscope, but at B, the force of gravity (inversely proportional to the square of the distance of a body from the earth) will drain mercury from cup 2 to cup 1. Now the unsymmetrical displacement of the mercury will produce a torque on the gyroscope, turning it to the position shown at C, where its axis lies parallel to that of the earth. No further torque is applied as the attraction of the earth towards the mercury in cups 1 and 2 is equal. Although this is only a very crude outline of the Gyro-Compass, it is apparent that such an instrument will take a long time to lie in a fixed direction, and even when used on ships the compass is subject to errors from acceleration forces, so for these reasons it is never used in this form of aircraft. Modified instruments, however, are used, where the gyroscope is made to follow a magnetic compass, a torque being applied whenever its position differs from that of the compass. This combined instrument is not subject to accelerational errors so much as a magnetic compass would be.

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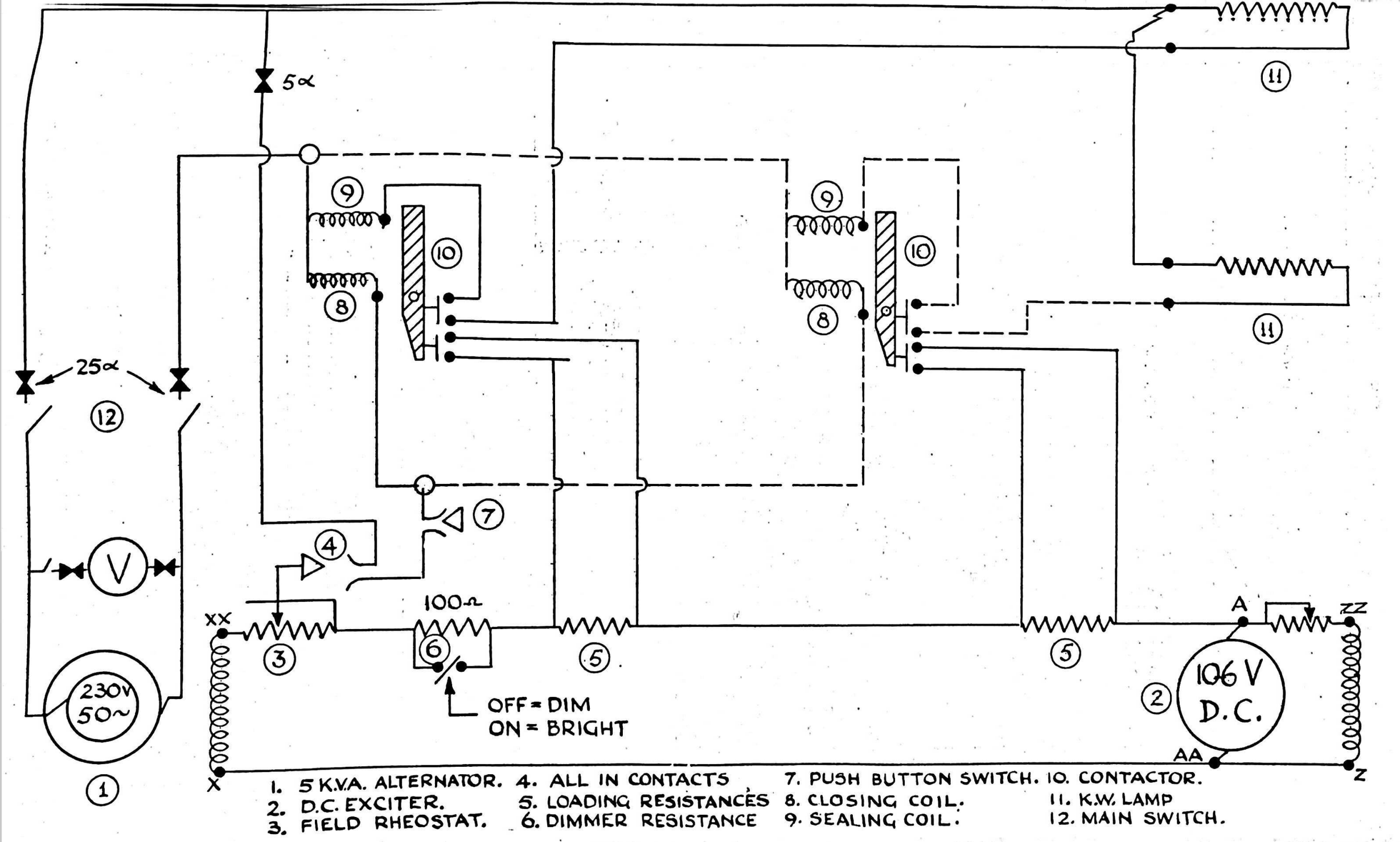
Aircraft Gyroscopic Flight Instruments - Sperry, Brentford, 1948.


5∝
25∝
12
11
9
10
8
7
4
V
100Ω
XX
3
6
5
OFF = DIM
ON = BRIGHT
A
N
106 V
D.C.
2
AA
Z
230V
50~
1
X
1. 5 K.V.A. ALTERNATOR.
2. D.C. EXCITER.
3. FIELD RHEOSTAT.
4. ALL IN CONTACTS
5. LOADING RESISTANCES
6. DIMMER RESISTANCE
7. PUSH BUTTON SWITCH.
8. CLOSING COIL.
9. SEALING COIL.
10. CONTACTOR.
11. K.W. LAMP
12. MAIN SWITCH.

PROGRESS AND EFFICIENCIES OF LIGHTING UNITS

FILAMENT LAMPS

GAS DISCHARGE. LAMPS.

EFFICIENCY LUMENS PER WATT

60
50
40
30
20
10
0

CARBON ARC
1858

CARBON LAMP
1879

METAL FILAMENT
1909

GAS FILLED
1913

GAS FILLED COILED COIL
1934.

HIGH POWER PROJECTOR

NEON TUBE
1922

1932
SODIUM

1932
MERCURY VAPOUR

FLUORESCENT
1940

POOR

FAIRLY GOOD

VERY POOR

VERY GOOD

ELECTRICAL & INSTRUMENT SECTION

HENLOW DIVISION, R.A.F. TECHNICAL COLLEGE.

AUTOMATIC PILOT. Mk.8. (Ref. AP.1469C. Vol.1)

Instrument Precis No.10

Introduction (pp.20-47)

Pneumatic control, operation on 60 lb/sq.inch pressure, fitted on aircraft to reduce strain and fatigue to the human pilot. The system is so arranged that the ailerons control aircraft in both roll and yaw, (rudder not utilised), and the elevators controlling pitch.

Operates on the "displacement/displacement" system of control, i.e. degree of applied control surfaces proportional to degree of aircraft's disturbance.

Primary role - capable of flying an aircraft at a pre-determined attitude on a selected course at heights up to 32,000 ft. Secondary role - pitch changes and also two rates of turn may be achieved. Linked to the D.R. Compass for long term monitoring on course, controlled turns and "jinking" action.

COMPONENTS

"Arrow" Air Compressor. (pp.48-51A)

Engine drives, single-stage, eight-bladed rotary type - clockwise drive Lubrication by Oil, low temp. (34A/43) from auto-pilot oil system. Produces approx. 10 cu.ft./min. at 60 lbs/sq.inch up to 32,000 feet. Delivery connection incorporates oil control valve to prevent flooding of compressor when idle.

(a) Radial engines - compressor spline shaft engages in gear-box.
(b) In line engines - drive via a quill shaft and flexible coupling.

Compressor draining procedure (pp.163)

Compressor seizure (pp.164-166)

Oil Reservoirs Mks. 5 and 7 (pp.52-53A

Maintains reserve of oil for compressor and separates oil from compressed air.

Oil Cooler (pp.54)

Installed in slip-stream -fitted in pipe line between reservoir and oil inlet connection on compressor.

Automatic Valve (pp.55-57)

Prevents draining of oil feed to compressor when idle. Closes at $2\frac{1}{2}$ lb./sq.inch - fully opened at 7-8 lb./sq.inch. Arrow points in direction of oil flow.

Test Cock. Mk.4A. (pp.58-61

Provides a means of connecting an external source of compressed air when ground testing. Installed in pipe-line between reservoir and air-drier. Blocking cap has a vent to ensure seating of valve.

.../Air Intake

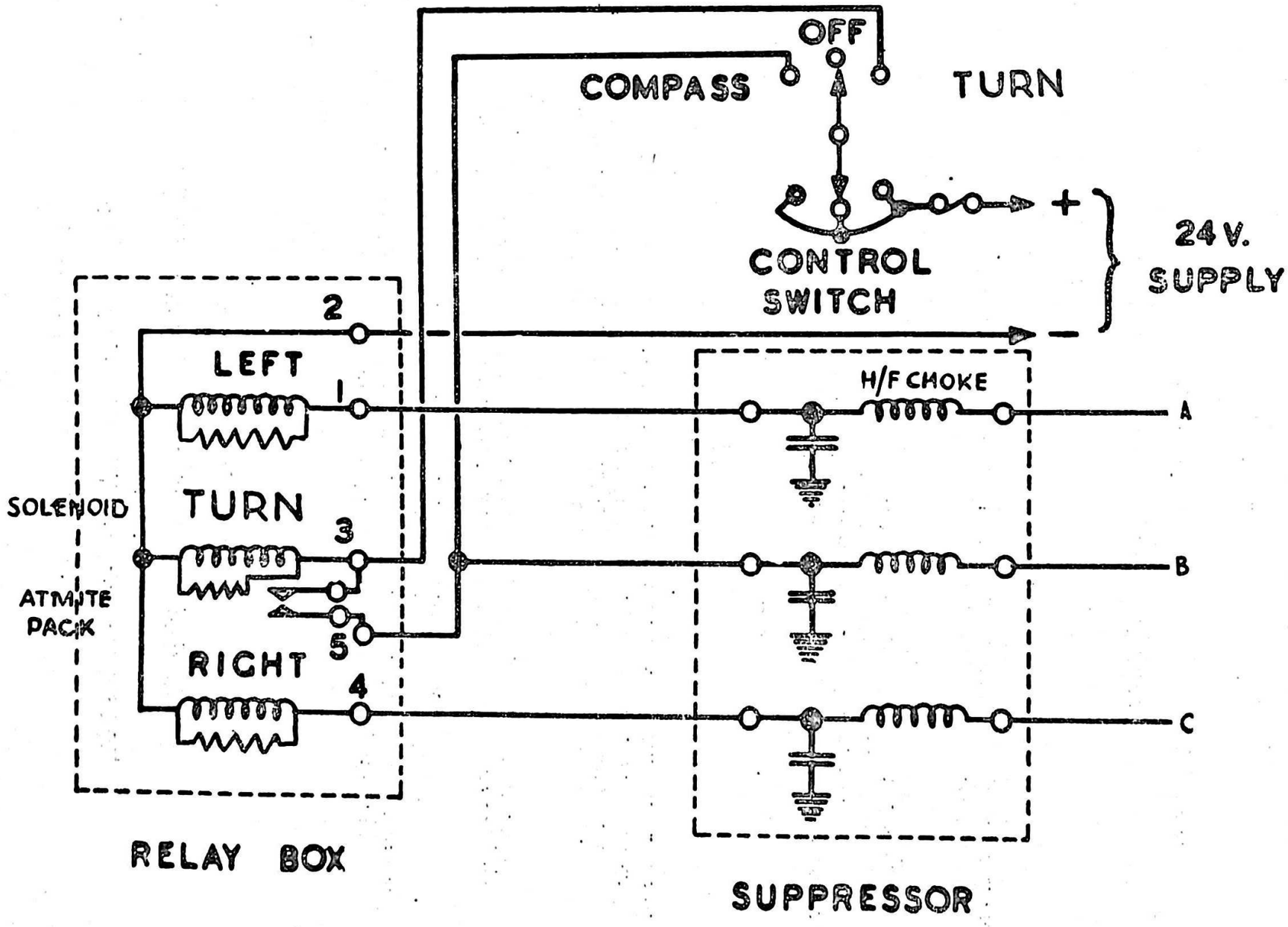
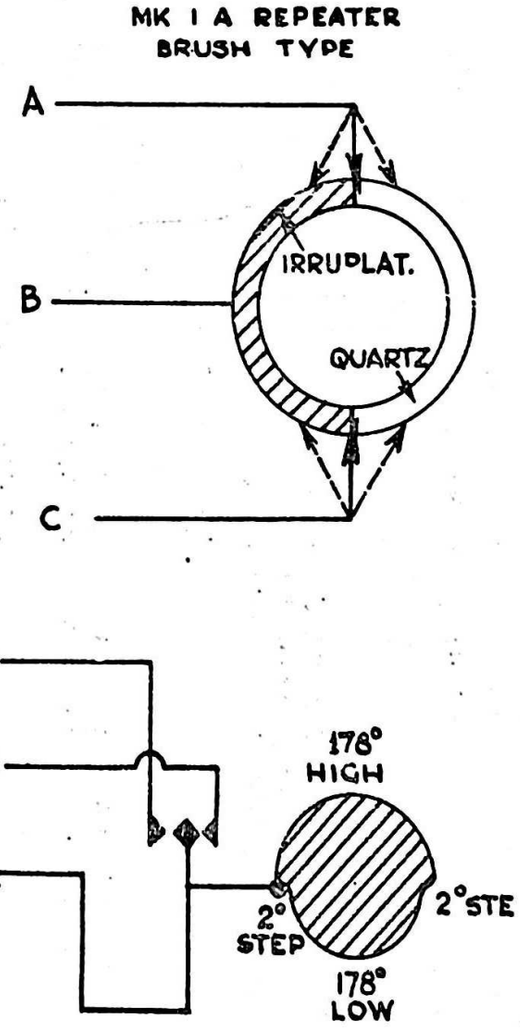
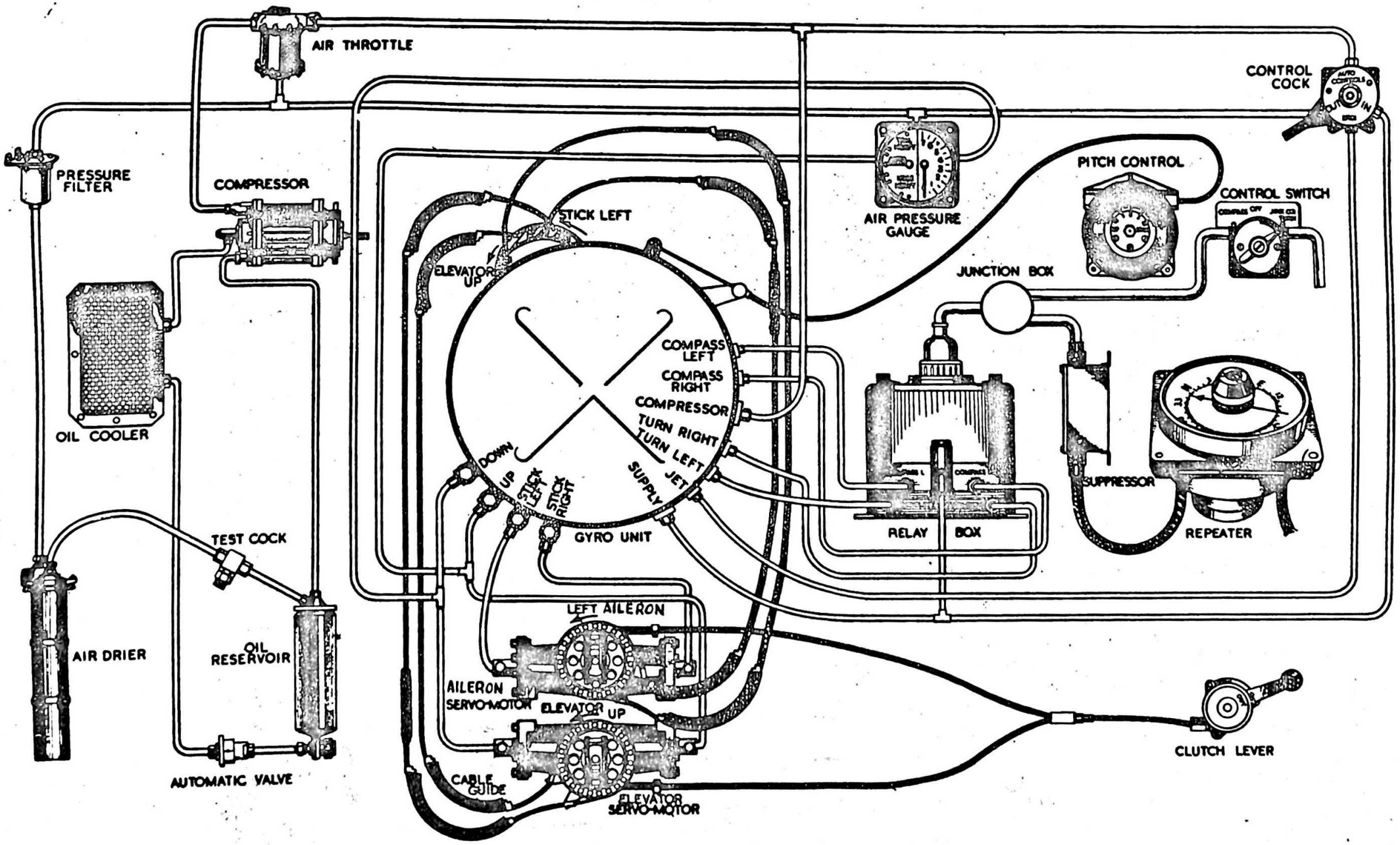


Fig. Schematic wiring diagram

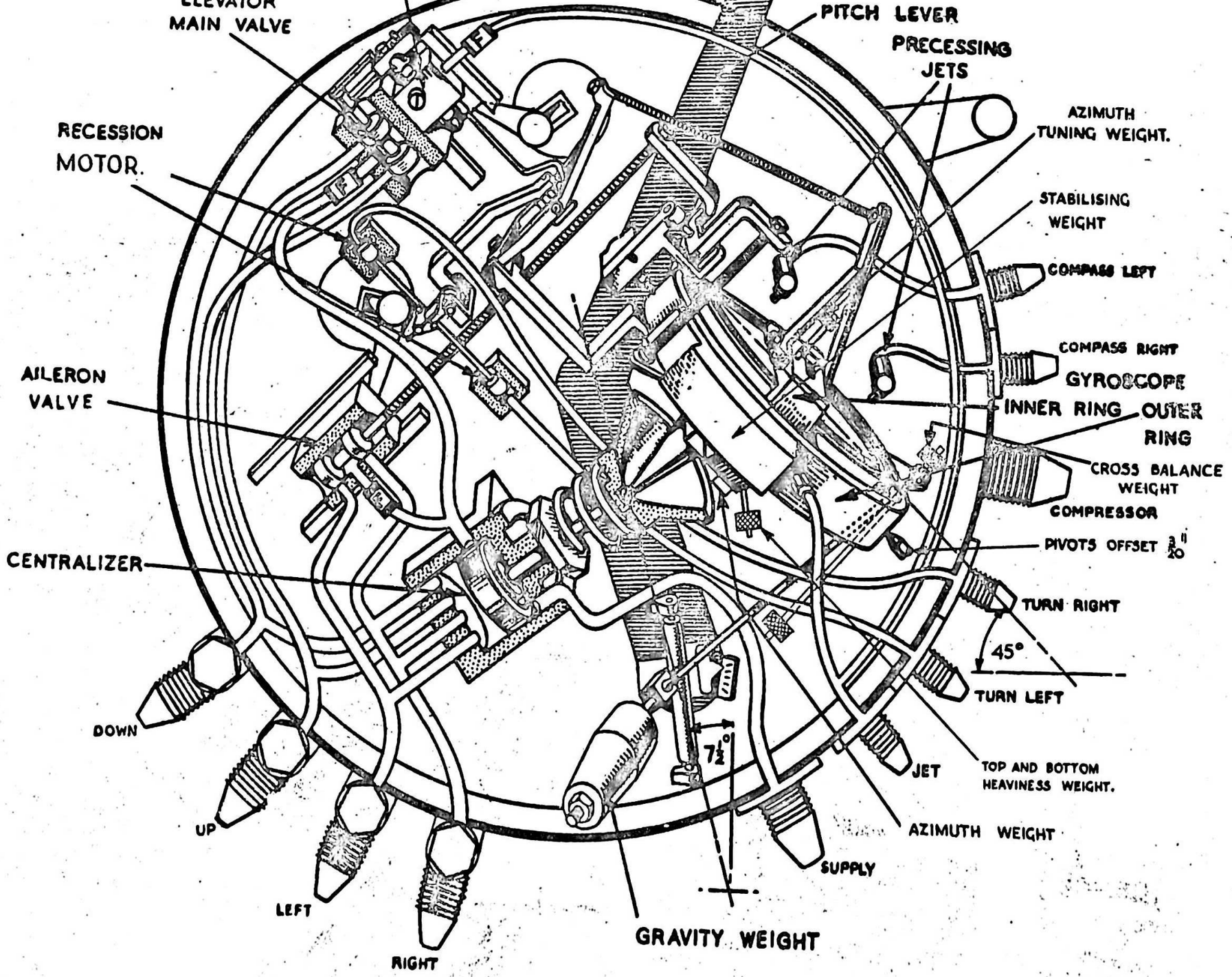


MK 1A REPEATER.



SCHEMATIC LAYOUT OF AUTOMATIC PILOT, Mk. 8

F.271



—Gyroscope unit. Diagrammatic

Air Intake Throttle (pp.132-134)

Regulates flow of air into compressor, thereby regulating delivering pressure at 60 lb/sq.inch. Enables air to enter system to provide for any deficiency - prevents oil reaching gyro-unit in event of blow-back. Installed in the regenerative pipe line to compressor and is also tapped into main pressure pipe line.

Air Driers. Mks. 5 and 6 (pp.63-64)

Installed in air pipe line immediately after reservoir to remove moisture. Drying agent - Silica Gel - requires changing every 10 engine hours, after compressor seizure and when detailed in servicing schedules.

Pressure Filter (pp.62)

Prevents Silica Gel Dust from entering gyro unit. To be renewed after compressor seizure and when detailed in servicing schedules. Installed in supply pipe line prior to control sock.

Control Cock Mk.4B* (pp.71-76)

Distributes pressure to system as required - enables pilot to engage and disengage auto-pilot at will. Choke fitted in exhaust connection to maintain a back pressure in system.

Three positions of handle:-

(a) "Out" - pressure back to regenerative system.

(b) "Spin" - pressure to spin jet and relay valve.

(c) "In" - pressure to spin jet, relay valves and servometers. (Autopilot engaged). Relay Bar, Centraliser and Main Valves.

Servo Motors (pp.127-131)

Two installed - transmit movement or relative movement of gimbol system to aircraft controls. Air pressure supplied to either end of servo-motors by respective main valve in gyro-unit.

Aircraft controls connected to servo-motor via a clutch mechanism. Movement of aircraft controls should exceed stroke of servo-piston in both directions.

Follow-up pulley on servometors connected by bowden cables to follow up pulleys on gyro unit.

Servo motor and plates, clutch lever, clutch bracket, follow up pulley, stop plate and control pulley may be assembled in several positions to suit installation requirements.

Combined Pressure Gauge (pp.136-137)

Indicates pressure in system and pitch trim of aircraft. Consists of three bourden tubes and mechanisms, one tapped into pressure pipe line, and the other two linked together and working in opposition being tapped into either side of elevator servometor.

.../Bomb

Bomb sight Cock (pp.78 and Appendices 2-3)

Means of connecting auto pilot air pressure system to the Mk.14 or S/A Bomb sights. When bomb sight cock is installed - choke is removed from control cock and fitted in B/S cock exhaust connection, air throttle intake is blanked and an extra air drier and filter is fitted in B/S supply pipe line. Supply may be taken from control cock exhaust connection - or supply pipe line prior to control cock. With the latter case, control cock exhaust connection is blanked and handle prevented by a suitable stop from being placed to "Out".

Pitch Attitude Control (pp.123-126)

Provided so that pitch changes may be accomplished. Connected to pitch arm at rear of gyro-unit by a bowden cable. Rocks pivoting system of gravity weight to vary application of torque to gyro.

Clutch Lever (pp.135B and 138)

Operates clutch mechanisms of servo motors. Linked to both servo motors by a bowden cable via a cable distribution box.

Gyro Unit Mk.8* (pp.8-14 & 81-106)

Gimbol System (pp.86-88)

Provides a datum, controlling the valve mechanisms which in turn operate the aircraft controls.

Outer gimbol ring pivoted top and bottom, tilted 45° back from vertical detects roll and yaw disturbances (Sin 45° = .7071 . . gyroscope 70% effective in correcting roll and yaw disturbances. This is compensated by adjustment to aileron follow up ratios). Bottom bearing facilities flow of air to spin jet - also spring loaded to reduce shock.

Inner gimbol ring pivoted horizontally athwartships - detects pitch disturbances. Rotor speed approx. 20,000 r.p.m. - gimbol rings weighted to make gyro earthbound.

Gravity Control Weight (pp.103-106)

(a) Precesses inner gimbol ring to make gyro conform to earth's curvature.

(b) Prevents inner-ring wander.

(c) Means of controlling aircraft's pitch attitude.
Tilted $7\frac{1}{2}^{o}$ back from vertical to tension linkage and prevent breakage.

Azimuth Balance Weight

Precesses outer gimbol ring to conform to earth's rotation.

Azimuth Tuning Weight

Adjusted in conjunction with Azimuth Balance weight to compensate for earths rotation at a specific latitude.

Top and Bottom Heaviness Weights

Brings C.G. of inner ring in line with its pivots - prevents course changes during pitch changes.

.../Cross Balance

Cross Balance Weights

Brings C.G. of outer ring in line with its pivots - preventing pitch changes dur ng turns

Stabilising Weight

Compensates for:-

(a) 3/20" off-centre pivoting of outer ring. (Due 'o us of Mk.4 Auto pilot jigs).

(b) Tilting of Gravity Control weight pivoting system.

Main Valves (pp.89-91)

Linked to gimbol rings - permit movement or relat ve movement of gyroscope to create differential pressure in servo motors, and subsequent operation of rcraft controls. Thrust on servo pis ons proportional to valve displacement.

Aileron valve piston attached to outer ring - elevator valve piston attached to inner ring. Linkage system consists of spr tensional rods which prevent loss of linear movement whilst permitting slight lateral movement. Valve bodies located in slides are moved in the r slides by the follow up mechanism.

Relay Valve. Mk.8[2] (pp.92-96B)

Purpose - prevents friction of elevator valve from applying back-torques which would result in yaw wander. Fitted to elevator valve, providing a pneumatic link between that valve and the inner-ring. (Not necessary an aileron valve because of stabilisatio by Gravity We ght). Operated on 7-9 lb/square inch pres ure when ontrol ock is at "Spin".

Action in event of pressure supply failure to Relay Valve. (pp.96C)

(a) Secondary and elevator valve pistons drop downwards applying down elevators.

(b) Aircraft dives - follow up action moves valve bodi s down in their slide.

(c) Spring loaded washers on primary piston linkage limit movement of secondary piston to 1/32 inch approx.

(d) Application of control limited - dive should not exceed 2 degrees.

(e) Leaf spring and spring loaded washers cause secondary piston to be mechanically linked to inner-ring - short circuiting the faulty relay valve.

(f) Auto pilot's performance deteriorates - but allows pilot to take over comfortably.

Follow up System (pp.15-19 & 100-100A)

Purpose - to limit amount of applied control proportional to disturbance i.e. valve displacement, thus preventing over correction and over shooting. (Aircraft may still overshoot due to its momentum - but this gradually reduces to zero). Follow up ratio lever has graduated datums provided to adjust throw of crank to meet installation requirements.

.../Action

Action - Servo motor applied aircraft controls simultaneously rotating follow up pulley which is connected to gyro unit follow up pulley by an endless bowden cable. (This cable is spring tensioned and may have a series of frictionless roller guides for negotiating bends). As the latter pulley rotates, it operates via a reduction gearing the ratio lever moving valve body in its slide. Direction of movement tending to centralise the valve.

Situation of Datums

(a) One on each valve slide.
(b) Seven on each ratio lever.
(c) One on pitch arm.
(d) Three on each follow up pulley.
(e) Five on follow up pulley plate.
(f) 35-55 degree settings or gravity weight system.

Modifications Gyro Unit. Mk.8* (pp.96A & 100A)

Centraliser (pp.101-102)

(a) Control cock at "Spin" or "Out"
Centraliser piston forward under spring tension:-

(i) Gyroscope caged in orthogonal position
(ii) Servo motors exhausted.

(b) Control cock at "In"
Centraliser piston held back under air pressure.

(i) Gyroscope freed.
(ii) Air pressure supplied to main valves.
(iii) Servomotor exhaust parts blanked.

Compass Jets (pp.97-98)

Precess outer gimbol ring at rate of 3-5 degrees/minute in required direction when autopilot is monitored by the D.R. Compass. Supplied with air pressure when necessary by the Relay Box.

Precession Motor (pp.99)

Precesses outer gimbol ring at 120 degrees per minute, approx. in required direction during controlled fast turns and "jinking" action. Supplied with air pressure by Relay Box.

Electrical System (pp.119-122 & Fig.64)

Autopilot is linked to the D.R. compass for long term yaw monitoring also for achieving slow or fast turns and automatic "jinking" action.

Relay Box (pp.37 and 111-116)

Distributes air pressure to either side of precession motor or compass jets as appropriate. Consists of three valves - interconnected operated by 24v. D.C. solenoids. Centre solenoid energised by control switch being placed to "Turn". When energised, centre solenoid also makes a pair of contacts completing 24v. positive supply to Mk.1A Repeator. Centre valve directs air pressure either to compass jets (solenoid de-energised) or to precession motor (solenoid energised).

.../End

End solenoids energised by Mk.1A Repeater pointer being deflected from lubber line. The end valves, dependant upon solenoid energised, govern direction of gyro precession.

Control Switch (pp.38 and 117)

(a) "Off". Autopilot electrical supply broken. Accuracy of course keeping dependant upon gyroscope balance.

(b) "Compass". Gyroscope monitored by D.R.C. Slow rates of turn can be achieved.

(c) "Turn". Fast turns or automatic "jinking" action can be achieved.

Interference Suppressor (pp.118)

Installed in system between relay box and pilots repeater Mk.1A. Consists of an H/F choke in series with the lead and a condenser between the lead and earth.

Pilot's Repeater. Mk.1A. (pp.36 & 107-110)

Indicates heading of aircraft and is a means of monitoring the aircraft on any desired heading or turning the aircraft on to any desired heading, whilst flying under automatic control. Essentially part of the D.R.C. installation but is also connected to the auto pilot electrical system.

Brush type. Consists of three slip rings mounted on the base of the repeater, centre ring being 180 degrees irruplat, (conductive) and 180 degrees quartz (non-conductive) former supplied with 24v positive. Two outer slip rings connected to "left" and "right" solenoids respectively, in relay box. A brush assembly linked to tail of repeater pointer moves over these slip rings when pointer is deflected. Inner pair of contacts on brush assembly are set 178 degrees apart over quartz segment when pointer is on lubber line - giving a 2 degrees dead gap for neutral position.

Cam type. A cam 178 degrees high 178 degrees low, with two 2 degree steps, (providing neutral positions) is linked to tail of repeater pointer. Two fixed contacts are connected to "left" and "right" solenoids in relay box. Between this pair of contacts is a moving contact, supplied with 24v positive, positioned by an actuating lever which rides on the cam.

Procedure for "Engaging" the Auto-Pilot (pp.171-172)

Prior to Take-Off

(a) Engage clutches
(b) On engine run-up ensure 60 lb/square inch pressure and freedom of controls.
(c) Switch on D.R.C.

When Airborne

(a) Control cock to "Spin". (To be at "Spin" for minimum of 5 minutes before engaging).

(b) Switch to "Compass" and set repeater pointer to lubber line.

(c) Trim aircraft to fly "hands and feet off" at desired speed, course and attitude.

(d) Set pitch attitude control to attitude of aircraft.

(e) Control cock to "In" - check engagement of controls by feel of column.

.../Trimming

Trimming Aircraft whilst Auto Pilot is Engaged (pp.173-174)

Pitch Trim

Adjust elevator trimmers in normal manner - with reference to combined pressure gauge.

N.B. Pitch attitude can only be altered by using the Pitch attitude control - DO NOT attempt to change attitude by operation of elevator trimmers.

Lateral Trim

Trim on same side rudder as wing is low.

Example:- Incorrect trim of rudder to port would give a tendency for aircraft to turn to port. This is detected by the autopilot as a port disturbance which, will apply ailerons to bank aircraft to starboard. Balance is areached when sufficient aileron is applied to oppose incorrect rudder trim. Result - aircraft maintaining course but flying starboard wing low. Remedy - trim rudder to starboard, thereby removing the disturbing factor and aircraft will level out.

Flight with one or more engines out

(a) Control cock to "Spin".
(b) Feather propellers of U/S engines, but if compressor is mounted on a U/S engine windmill that propellor to give a minimum pressure of 45 lb/sq.inch.
(c) Trim rudder to maintain straight flight. (If full rudder bias is insufficient - assist by force on rudder bar).
(d) Control cock to "In".

Procedure for "Disengaging" Autopilot (pp.175)

(a) Control cock to "Spin".
(Aircraft should be trimmed and P.A.C. re-set if necessary prior to re-engaging.)

Prior to landing
(b) Control cock to "Out".
(c) Control switch "Off".

N.B. Clutches should not be disengaged except in an emergency.

Pitch Disturbance (pp.8-9)

Example:- Nose-down disturbance

(a) Disturbance occurs - relative movement between inner gimbol ring and aircraft.

(b) Elevator valve body moves down over its piston.

(c) Variation of pressure in elevator servomotor.

(d) Servo applies up-elevators to check the disturbance.

(e) Simultaneously follow-up action moves valve body up in its slide - limiting amount of corrective control.

.../(f)

(f) Due to applied control - aircraft commences to return to original attitude.

(g) Relative movement between inner-gimbol ring and aircraft.

(h) Elevator valve body moves up over its piston.

(j) Variation of pressure in servomotor.

(k) Servomotor removes applied control.

(l) Follow-up action moves valve body down in its slide.

(m) Any overshoot, (due to momentum of aircraft) treated as a similar disturbance but in the opposite direction).

(n) Aircraft back in its original attitude but at a slightly reduced altitude, with servo, valves and control central.

Note: Assistance of gravity weight during pitch disturbances is negligible.

Roll and Yaw Disturbances (pp.10-14)

Relative movement occurs between outer gimbol ring and aircraft, subsequent movement of aileron valve applies corrective aileron control. Similar sequence of operations to that of a pitch disturbance.

Note: Assistance of monitoring system is negligible during disturbances.

Change of Pitch Attitude (pp.103-106)

(a) Set pitch attitude control to required dive or climb.

(b) This tilts gravity weight pivoting system upsetting balance.

(c) Torque on outer gimbol ring precesses inner gimbol ring.

(d) Elevator valve piston moves through valve body.

(e) Variation of pressure in servomotor.

(f) Servo applies elevator control.

(g) Follow-up action moves valve body in its slide - tending to centralise valve.

(h) Aircraft changes pitch attitude until desired new attitude is attained.

(j) Balance between gravity weight and gimbol system is regained - torque removed.

(k) New pitch datum has been set.

(l) Due to applied controls - aircraft tends to continue changing attitude.

(m) Relative movement between inner gimbol ring and aircraft causes elevator valve body to move over piston.

(n) Variation of pressure in servomotor removes or sufficiently reduces elevator control.

(o) Follow-up action centralises elevator valve.

(p) Adjust on elevator trimmers if necessary.

(q) Any tendency to deviate from the selected attitude treated as a pitch disturbance.

.../Compass

Compass Monitoring (pp.36 amd 119-122 & 173)

Example:- Gyro wanders clockwise

(a) D.R.C. - "on" - control switch at "Compass".

(b) Aircraft deviates off selected heading to starboard.

(c) Repeater pointer moves contact assembly out of neutral position.

(d) "left" solenoid in relay box is energized.

(e) Port compass jet (top jet) precesses gyroscope anticlockwise at 3-5 degrees/min.

(f) Aileron valve piston moves through valve body.

(g) Variation of pressure in aileron servo-motor.

(h) Servomotor applies aileron, banking aircraft to port.

(j) Follow-up action limits application of control.

(k) Aircraf respond to control turning to port until it is on its origina he ding, i e. on a track parallel to its original track.

(l) Repeater pointer reaches lubber- ne "left" solenoid re-energised and torqu removed.

(m) Due to applied control, aircraft tends to continue turning relative valve movement occurs.

(n) Variation of pressure in aileron servomotor control removed and follow-up action centralises valve.

(o) Aircraft in level flight on original heading.

Course Changes (pp.36 and 119-122 and 173)

(a) D R.C. "on".

b) Set pitch attitude control 5 degrees nose up.

(c) Deflect repeater pointer to desired new heading.

(d) Control switch to "Turn".

(e) Centre and either "left" or "right" solenoid in relay box are energised.

(f) Precession motor precesses outer gimbol ring at 120-180 degrees per minute.

(g) Aileron valve piston moves through body.

(h) Variation of pressure in aileron servomotor.

(j) Ailerons applied - limited by following action.

(k) Aircraft responds to controls - turns in required direction.

(l) Aircraft attains bank angle sufficient to produce rate of turn equivalent to that of gyro precession. application of control automatically adjusted accordingly by relative movement of aileron valve.

(m) Control switches to "Compass" 15 degrees short of selected heading - centre solenoid in relay box de-energised.

(n) Precession motor out of action - compass jet in operation.

(o) Relative valve movement, aircraft levels out and follow-up action occurs.

(p) Aircraft monitored on to selected heading.

(q) Re-set pitch attitude control to its original setting.

.../Automatic

Automatic "Jinking" Action

(a) D.R.C. "on".

(b) Set pitch attitude control 5 degrees nose-up.

(c) Deflect repeater pointer from lubber-line.

(d) Control switch to "Turn".

(e) Similar sequence of events as for a fast course change - but switch should be left at "Turn".

(f) Aircraft overshoots selected heading and opposite control applied.

(g) Mild form of "jinking" action results - aircraft swinging approximately 15 degrees to either side of the mean heading previously set on repeater.

(h) Switch to "Compass".

(j) Reset the pitch attitude control to its original setting.

D.R. Compass U/S (pp.173)

Pilot's repeater can still be used as a turning switch (in conjunction with Directional Gyro or magnetic compass) should the D.R.C. become u/s.

(a) Switch "off" D.R.C.

(b) Control switch to "Compass", deflect repeater pointer in appropriate direction.

(c) Control switch "Off" when desired new heading is reached.

OR

(a) Switch "Off" D.R.C.

(b) Control switch to "Turn" and deflect repeater pointer in appropriate direction.

(c) Control switch "Off" 15 degrees before desired new heading is reached.

Installation

(a) A.P.1469C. Vol.1. pp.142-169 and Appendices 2-3.
(b) Relevant Aircraft Handbook.

Servicing

(a) A.P.1469C. Vol.1. pp.178-181.
(b) Relevant Aircraft Handbook.

Snag-Shooting

A.P.1469C. Vol.1. pp.184-204.

Pilot's Notes

(a) A.P.1469C. Vol.1. pp.170-177.
(b) Relevant Aircraft Handbook.

.../Ground

Ground Test (pp.167)

(a) External pressure supply 60 lb. per square inch to Test Cock.

(b) Control cock to "Spin" for minimum of 5 mins.

(c) Check autopilot electrical supply.

(d) Check servomotor over-rides and clutches.

(e) Check all datum alignments - adjust if necessary.

(f) Set pitch attitude control to attitude of aircraft.

(g) Engage autopilot - check engagement (may be necessary to damp elevator oscillation by holding control column).

(h) Check correct functioning of pitch attitude control.

(j) Check repeater dead-gap.

(k) Check correct functioning of compass jets.

(l) Check correct functioning of precession motor.

(m) Examine systems for air leaks.

(n) Control switch "Off", diengage autopilot set pitch attitude control to zero and disconnect external pressure supply.

Air Test (pp.163-169)

To be carried out by an Instrument N.C.O. after completion of a satisfactory ground test - minimum height 2,000 ft. Adjustments should be made when auto-pilot is disengaged.

(a) When airborne, with controls trimmed to fly "hands-off" check valve alignments - adjust if necessary.

(b) Engage autopilot.

(c) If controls "kick" upon engaging, disengage autopilot and readjust appropriate follow-up cable until auto-pilot takes over smoothly upon engagement.

(d) Check correct operation of pitch attitude control.

(e) Control switch to "Compass" - check rate of 3-5 degrees/minute in correct directions when repeater pointer is deflected.

(f) Control switch at "Turn" - check rate of turn is approximately 120 degrees/minute in correct directions when repeater pointer is deflected.

(g) Check "jinking" action.

(h) Control switch to "Compass", repeater pointer on lubber line check course monitoring.

(j) Disengage auto-pilot.